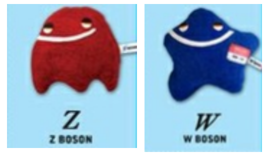
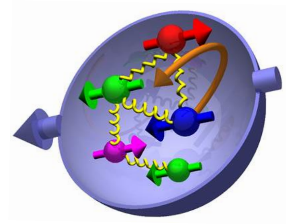
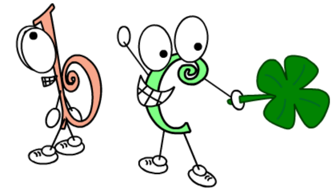


Sampling the QCD Soup with Massive Bosons and Heavy Flavor Jets

Ashish Kumar

on behalf of the D0 Collaboration

University at Buffalo
The State University of New York

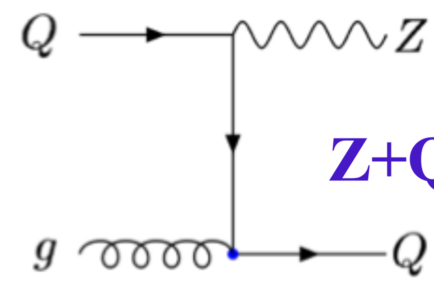
Fermilab Wine & Cheese Seminar, 07/19/2013

Outline

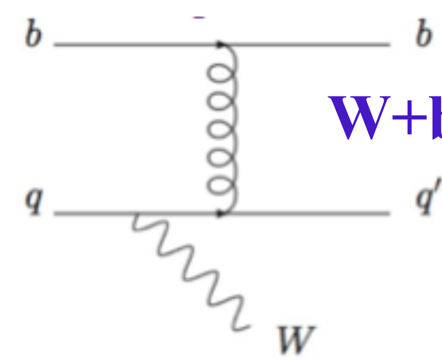
- Motivation
- The DØ Detector
- V(W/Z) + HF production
- Measurement Strategy
- Results
  - W+b
  - σ(Z+b)/σ(Z+j)
  - σ(Z+c)/σ(Z+j), σ(Z+c)/σ(Z+b)
- Conclusions

Motivation

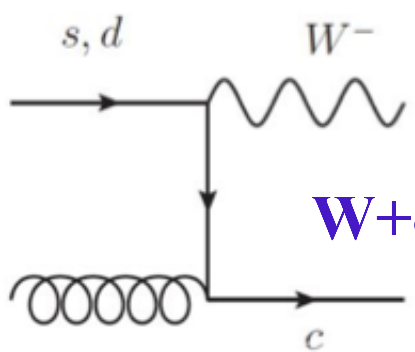
- Stringent test of perturbative QCD calculations
  - 5FNS and 4FNS schemes
  - Novel techniques: NLO + Parton Shower merging
- Validation of simulation models
  - Novel techniques for matching Matrix Elements with Parton Shower
- Sensitive to heavy flavor content of the proton



Z+Q (b/c)



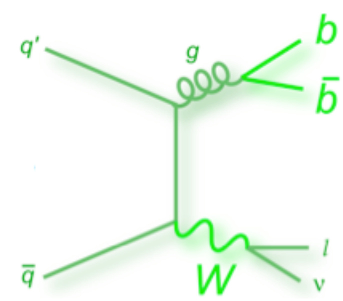
W+b

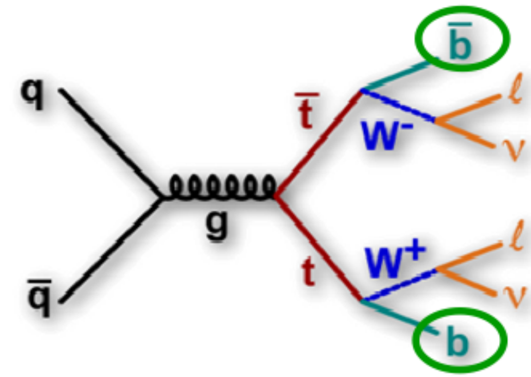


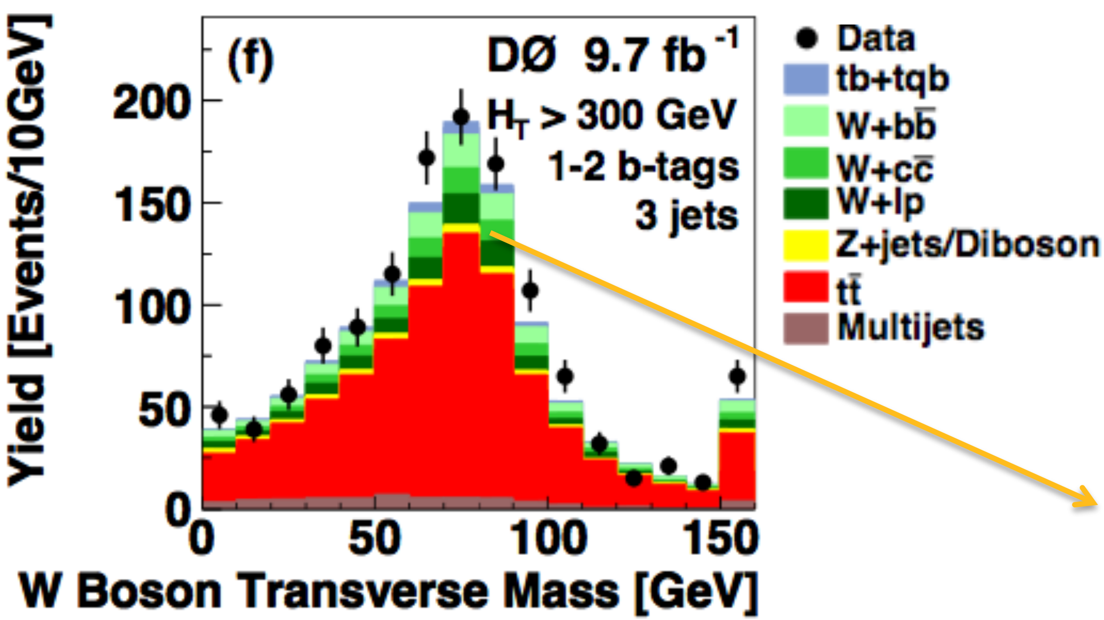
W+c

Motivation : Backgrounds to Top

- Irreducible backgrounds for variety of Standard Model processes and searches for new physics
  - Top quark properties
  - Study of Higgs Boson
  - SUSY searches



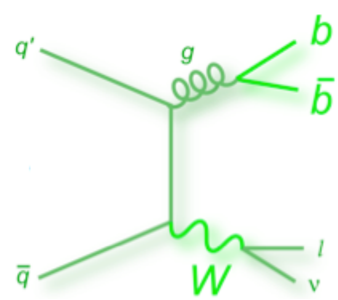


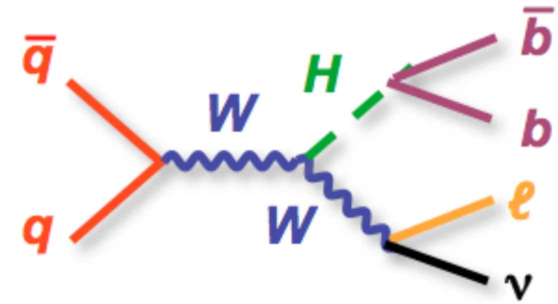


Evidence of s-channel single Top production: arXiv 1307.0731

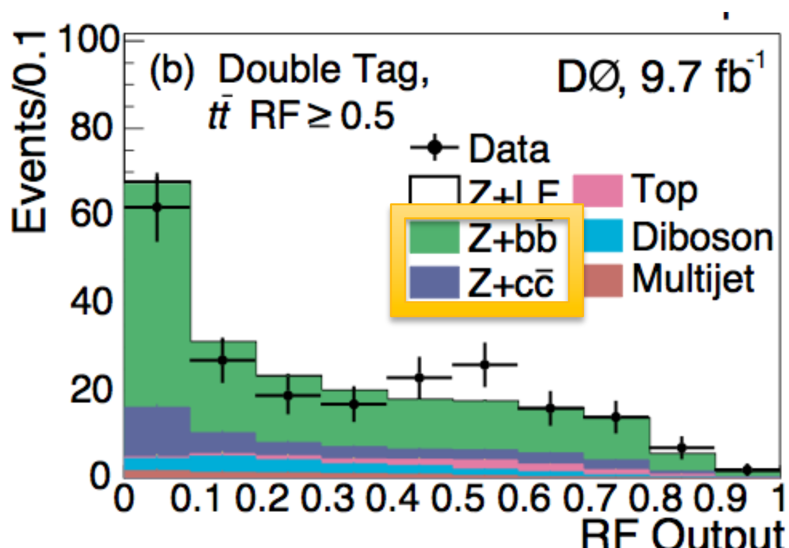
Relative Systematic Uncertainties	
Components for Normalization	
Integrated luminosity [44]	6.1%
$t\bar{t}$ cross section	9.0%
Parton distribution functions	2.0%
Trigger efficiency	(3.0-5.0)%
Jet fragmentation and higher-order effects	(0.7-7.0)%
Initial and final state radiation	(0.8-10.9)%
W/Z+jets heavy-flavor correction	20.0%
W+jets normalization to data	(1.1-2.5)%
Multijet normalization to data	(9.2-42.1)%

- Irreducible backgrounds for variety of Standard Model processes and searches for new physics
  - Top quark properties
  - Study of Higgs Boson
  - SUSY searches

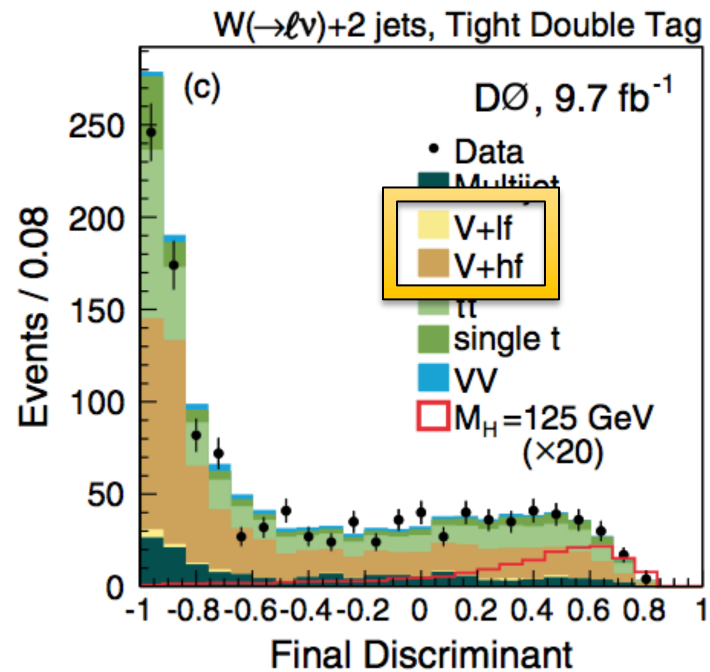




20-30% systematic uncertainty on the V+HF background normalization



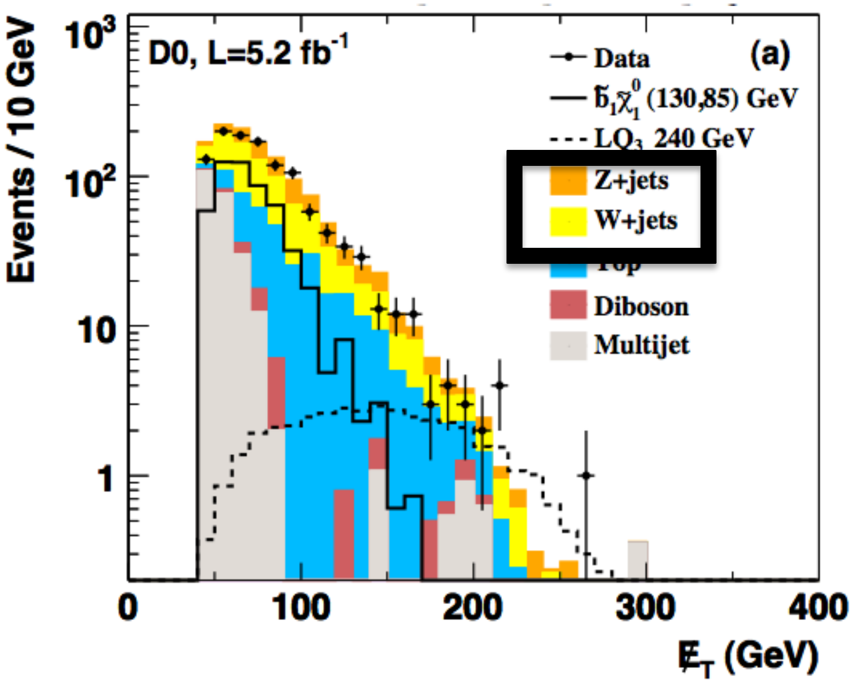
ZH(→bb)



WH(→bb)

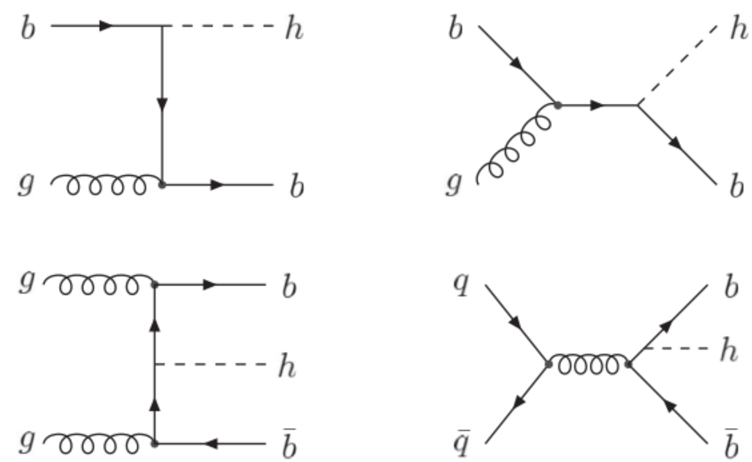
- Irreducible backgrounds for variety of Standard Model processes and searches for new physics
  - Top quark properties
  - Study of Higgs Boson
  - SUSY searches

$$p\bar{p} \rightarrow \tilde{b}_1\bar{\tilde{b}}_1 \rightarrow b\tilde{\chi}_1^0\bar{b}\tilde{\chi}_1^0$$



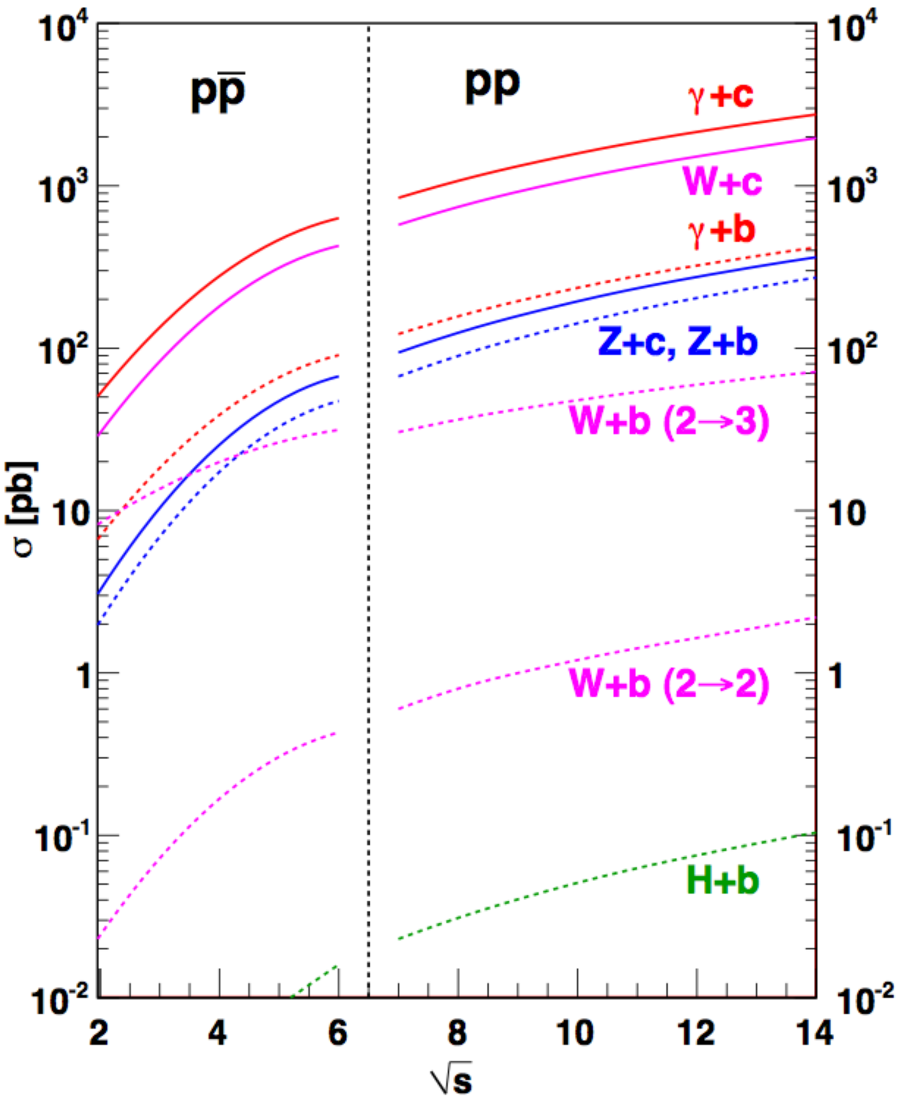
For SUSY Higgs production bh (→bb), bZ production serves as a reference QCD process

5-flavor



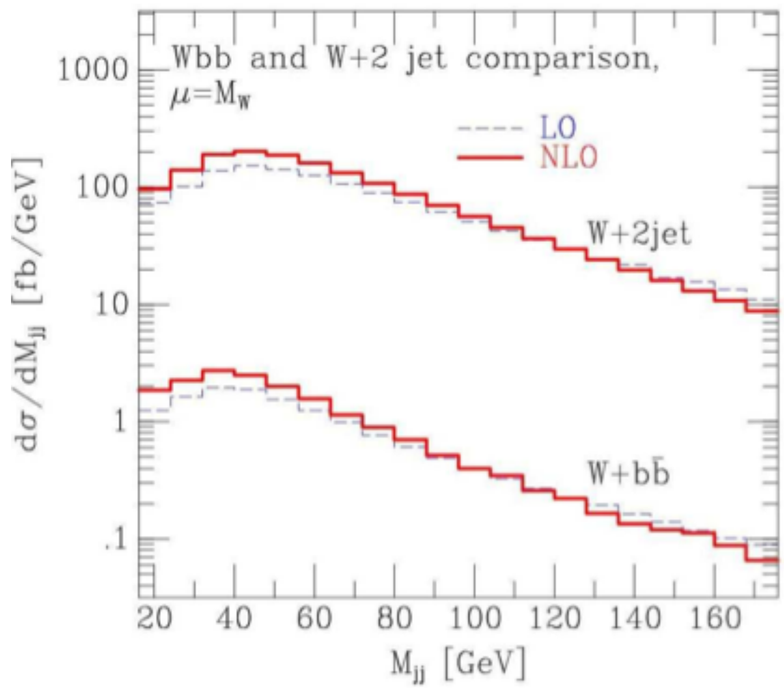
4-flavor

Production Rates



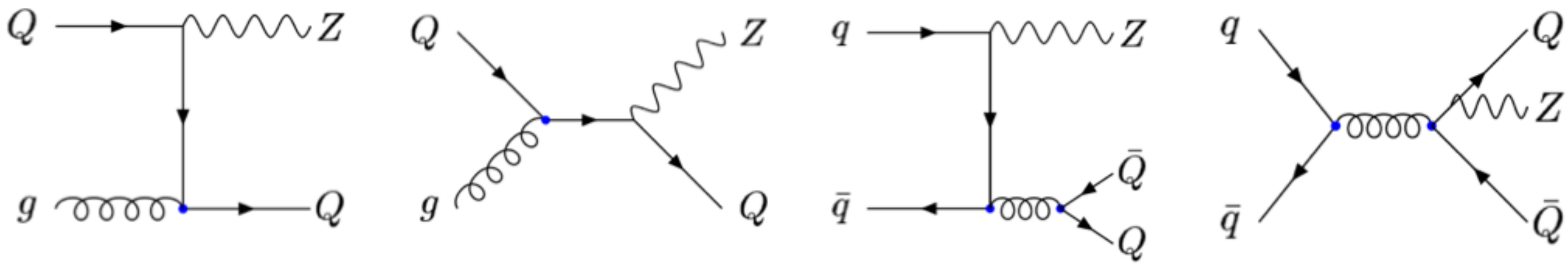
Courtesy: J. Campbell

- Small cross sections
- Measurements extremely challenging

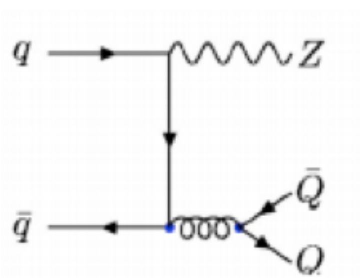


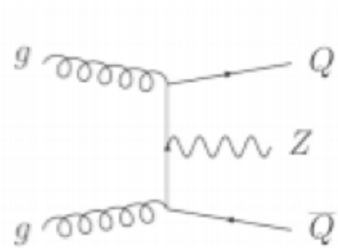
Z boson + heavy flavor (b/c) production

- **5 Flavor Scheme (MCFM): J. Campbell et. al.** PRD 69, 074021, 2004
  - Considers b-quark as massless and treats it as part of proton density. Includes contribution from merged quarks (part of same jet).



- **4 Flavor Scheme: D. Wackeroth et. al.** PRD 78, 074014, 2008

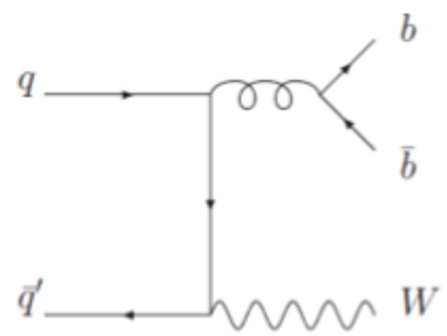




Massive b-quark ($m_b >> \Lambda_{QCD}$)

W boson + b-jet production

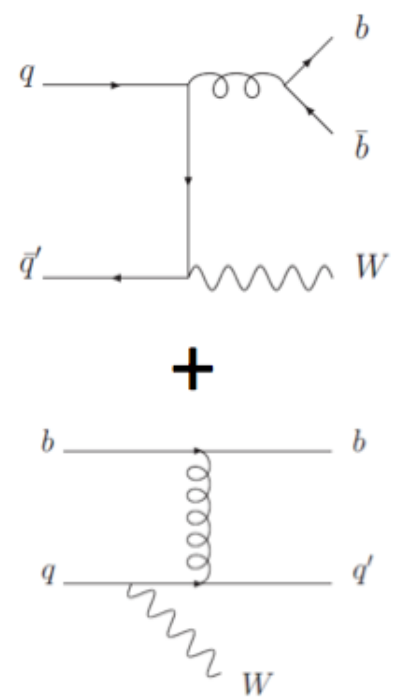
- **4 Flavor Scheme:**
  J. Campbell et. al. PRD 79, 034023, 2009



$O(\alpha_s^2)$

LO diagrams

- **5 Flavor Scheme (MCFM) :**
  J. Campbell et. al. PRD 75, 054015, 2007

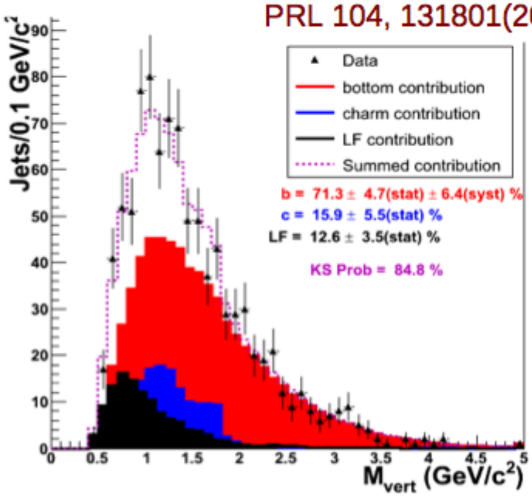


$O(\alpha_s^2)$

W + b-jets

CDF

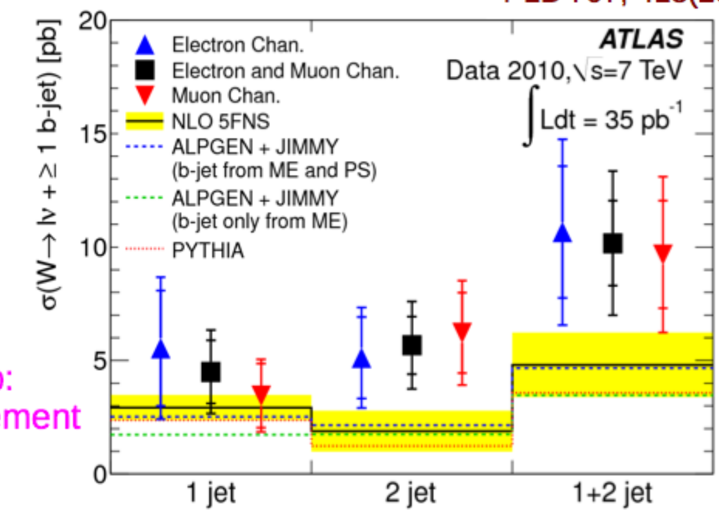
PRL 104, 131801(2010)



ATLAS

PLB 707, 418(2012)

W+1b: agreement



σ(W+b-jets) · BR(W → lν) [pb]:

Data: $2.74 \pm 0.27(stat) \pm 0.42(syst)$

NLO : 1.20 ± 0.14

$10.2 \pm 1.9(stat) \pm 1.6(syst)$

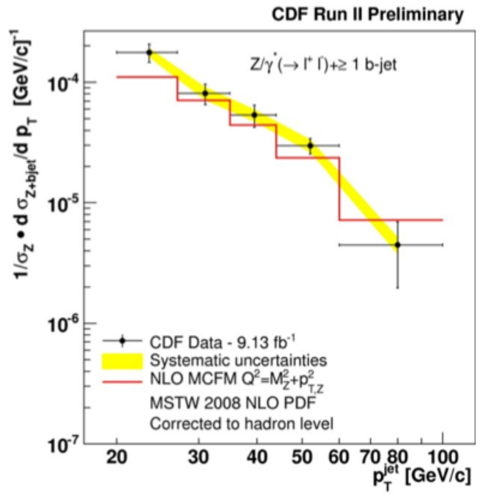
$4.8^{+1.2}_{-0.7}(scale)^{+0.3}_{-0.0}(PDF)^{+0.3}_{-0.2}(m_b) \pm 0.3(np.corr)$

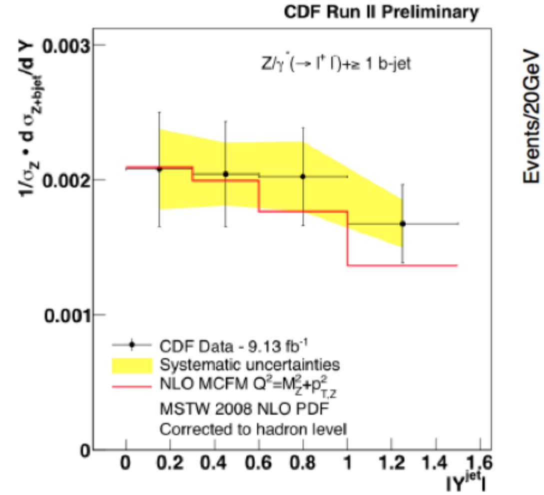
CDF

$$\frac{\sigma_{Z+bjet}}{\sigma_Z} = 0.261 \pm 0.023^{stat} \pm 0.029^{syst}\%$$

$$\frac{\sigma_{Z+bjet}}{\sigma_{Zjet}} = 2.08 \pm 0.18^{stat} \pm 0.27^{syst}\%$$

	NLO $Q^2 = m_Z^2 + p_{T,Z}^2$	NLO $Q^2 =< p_{T,jet}^2 >$
$\frac{\sigma(Z+b)}{\sigma(Z)}$	2.3×10^{-3}	2.9×10^{-3}
$\frac{\sigma(Z+b)}{\sigma(Z+jet)}$	1.8×10^{-2}	2.2×10^{-2}





D0 (PRD 83, 031105, 2011

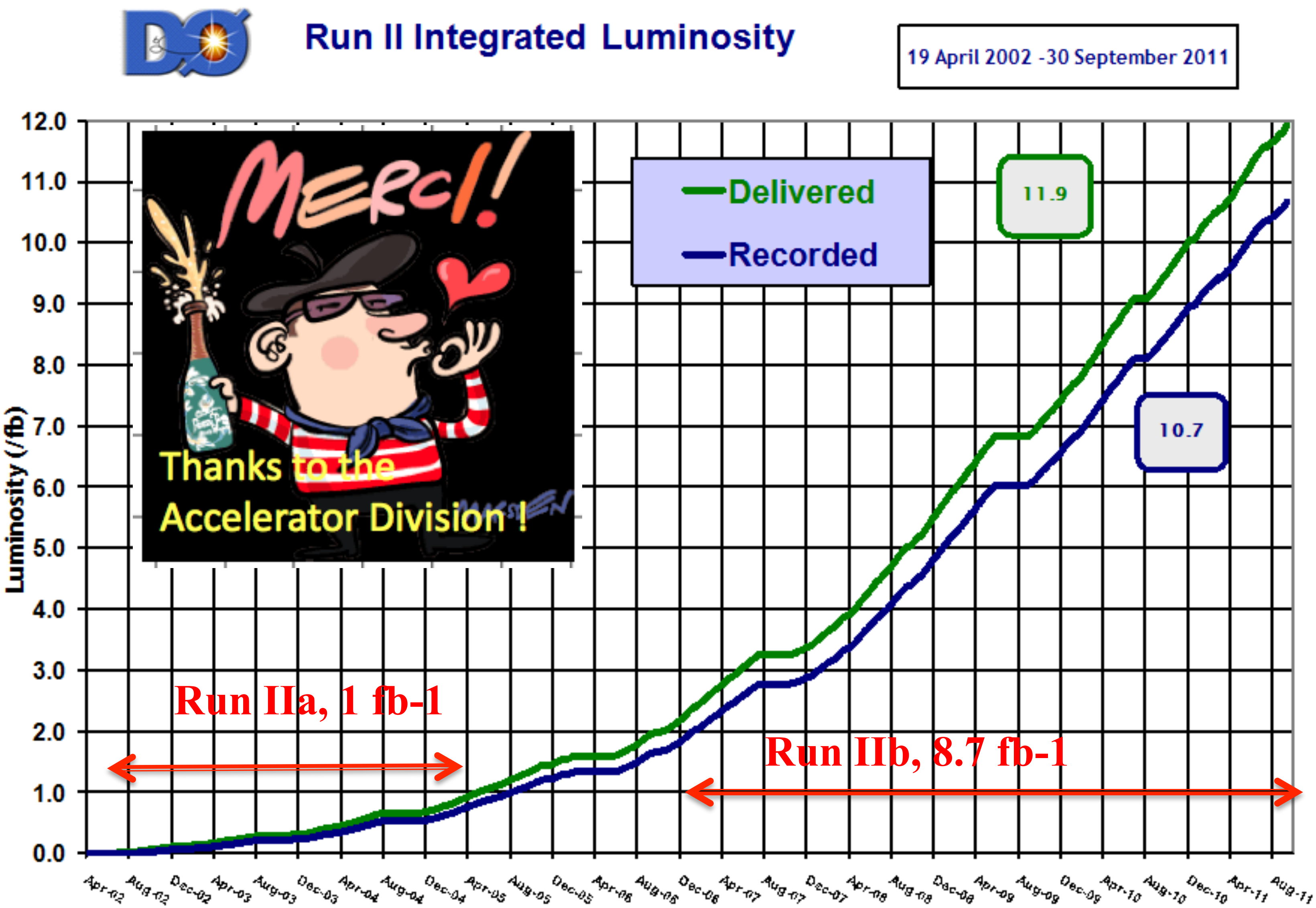
$$\frac{\sigma(Z + b\text{ jet})}{\sigma(Z + \text{jet})} = 0.0193 \pm 0.0022(\text{stat}) \pm 0.0015(\text{syst})$$

- Measurements of Z+b and Z+bb have been consistent with the predictions with 20-25% uncertainties.

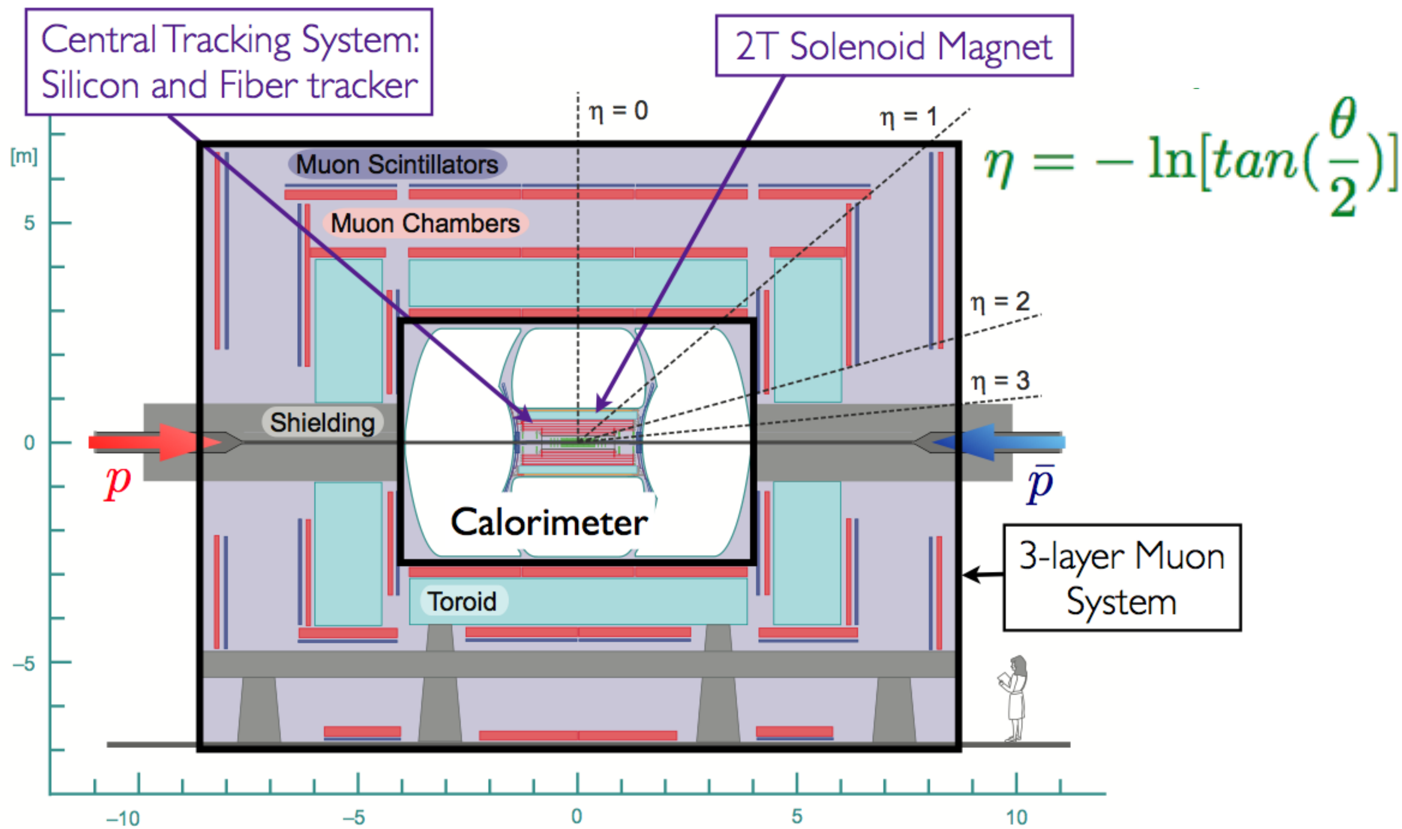
Recent Boson plus Jet Measurements by D0

Z+c-jet	9.7 fb-1	To be submitted to PRL (First measurement of Z+c-jet production)
Z+b-jet	9.7 fb-1	PRD 87, 092010 (2013)
Z+b-jet	4.2 fb-1	PRD 83, 031105 (2011)
W+b-jet	6.1 fb-1	PLB 718, 1314 (2013)
γ +b-jet	8.7 fb-1	PLB 714, 32 (2012)
γ +c-jet	8.7 fb-1	PLB 719, 354 (2013)
W+jets	6.2 fb-1	hep-ex/1302.6508

Data Sample


Run II Integrated Luminosity
19 April 2002 -30 September 2011
Delivered
Recorded
11.9
10.7
Luminosity (/fb)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02 Aug-02 Dec-02 Apr-03 Aug-03 Dec-03 Apr-04 Aug-04 Dec-04 Apr-05 Aug-05 Dec-05 Apr-06 Aug-06 Dec-06 Apr-07 Aug-07 Dec-07 Apr-08 Aug-08 Dec-08 Apr-09 Aug-09 Dec-09 Apr-10 Aug-10 Dec-10 Apr-11 Aug-11
MERCI!
Thanks to the
Accelerator Division !
Run IIa, 1 fb-1
Run IIb, 8.7 fb-1

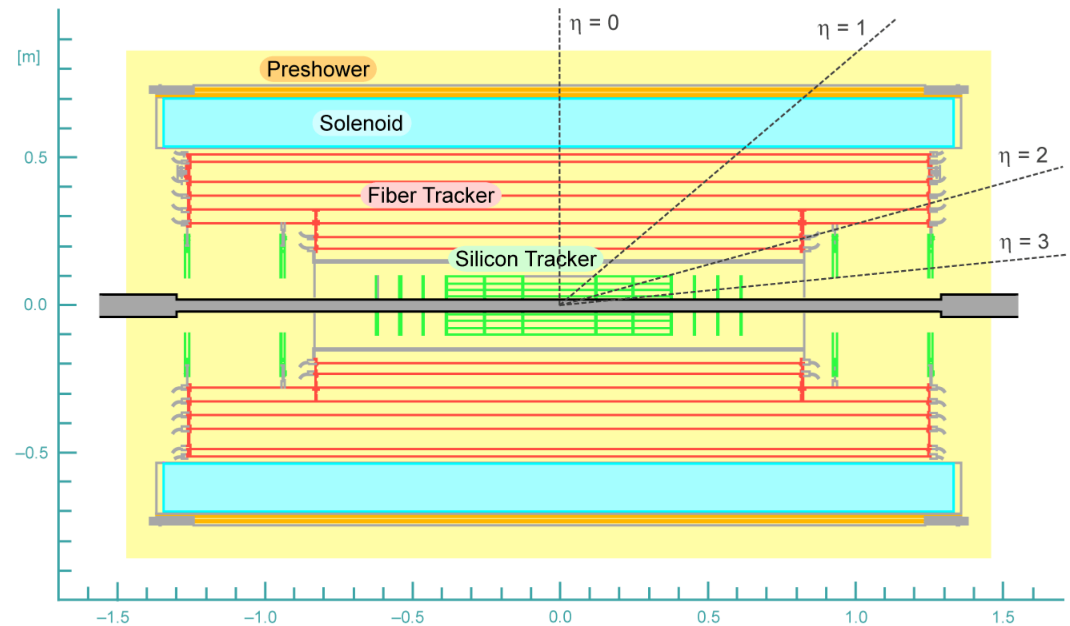
The DØ Detector

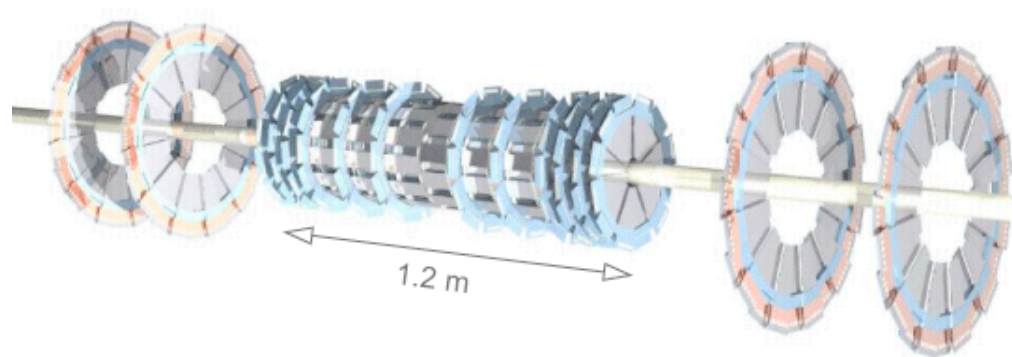


- **Tracking in magnetic field of 2T:**
  - **Silicon microstrip and central fiber tracker**
- **Calorimeter: Liquid argon sampling calorimeter**
  - **Central and Endcap, coverage : |η|<4.2**
- **Muon system: Drift chambers and scintillation counters,1.8 T toroid**

The DØ Detector: Tracker

- Important for heavy flavor jet identification
- Precise reconstruction of primary interaction vertex and secondary vertices: resolution ~35 μm
- Accurate determination of impact parameter of tracks: resolution ~15 μm

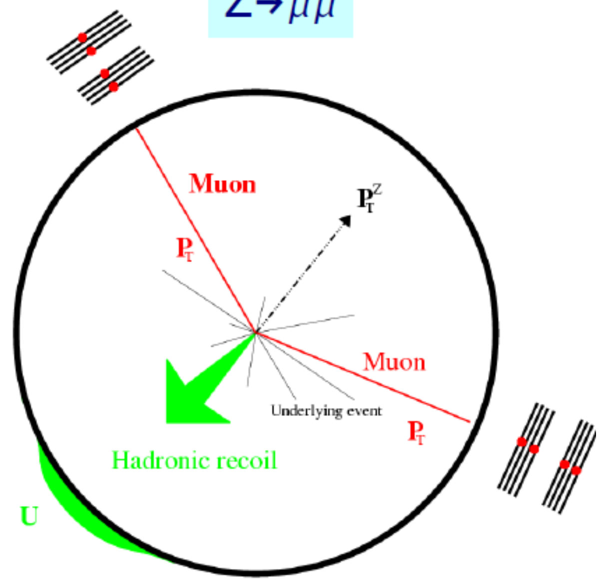




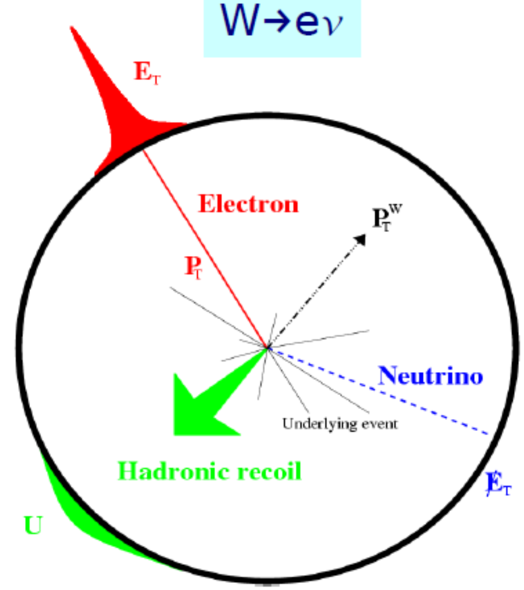
Event Reconstruction

- $W \to l\nu$ and $Z \to l^+l^-$ are identified with small background
- Z selection
  - Two high p_T leptons
- W selection
  - High p_T lepton
  - Missing E_T from undetected ν
- Electron
  - Isolated track and EM shower
  - Shower shape requirements
- Muon
  - Hits in Muon system
  - Isolated in tracker and calorimeter

$Z \to \mu\mu$

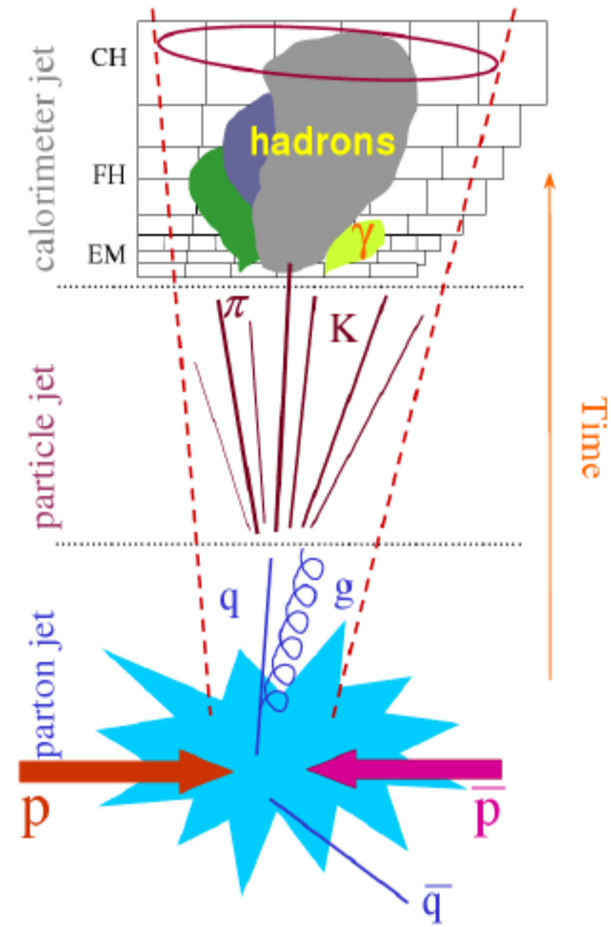


$W \to e\nu$

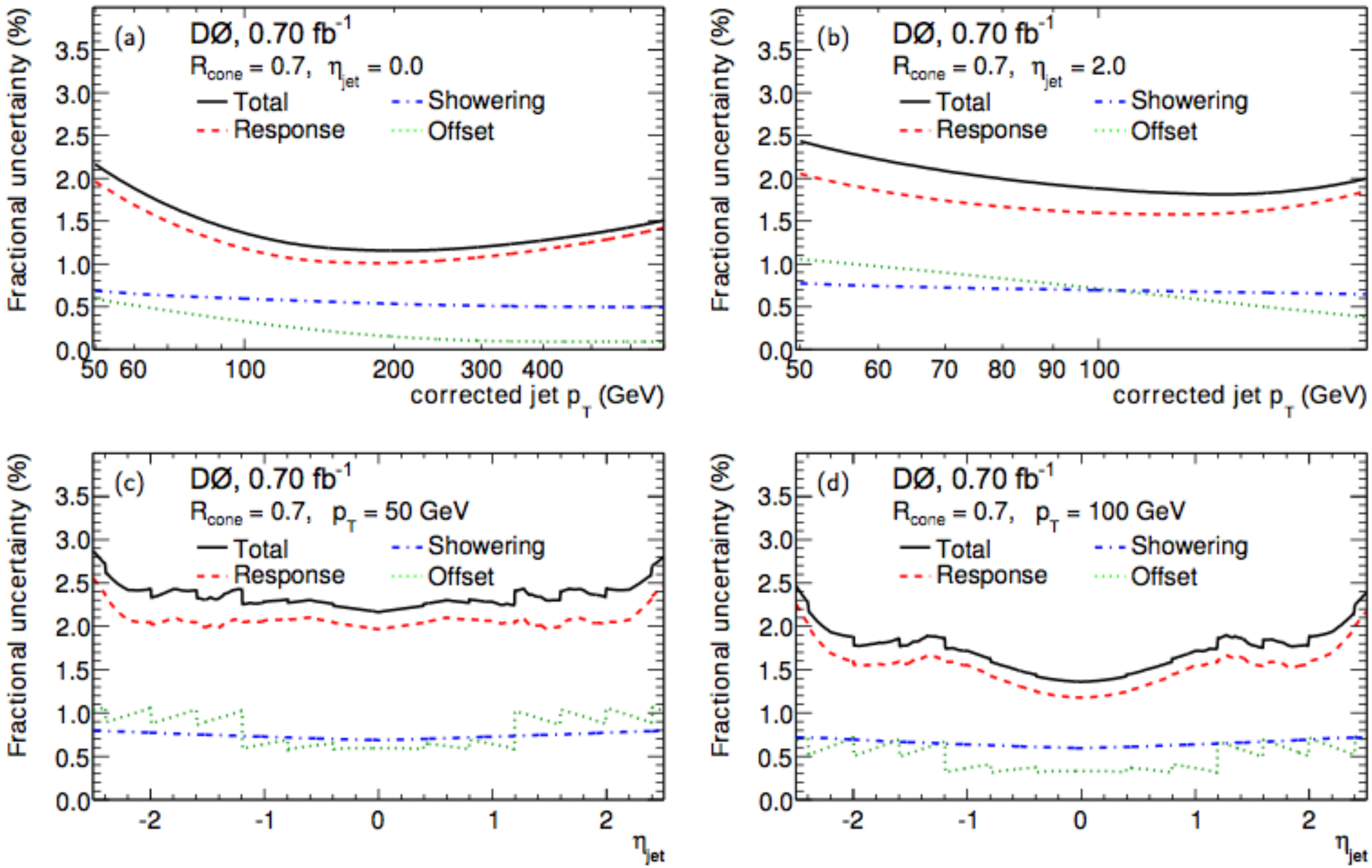


Jets

- **Reconstruction**
  - **Hadronic shower**
  - **Iterative mid-point cone algorithm, R = 0.5**
- **Jet Energy Scale**
  - **Measured in γ+jet and Dijet events**
  - **Correct energy to particle level**
  - **Correct for detector response, out of cone showering, overlap with pile up energy**
- **Correct parton-level theory for non-perturbative effects (hadronization and Underlying events) using parton shower Monte Carlo**



Jet Energy Scale Corrections



Measurement Strategy

- Select W/Z+jet candidate events

- Determine the fraction of W/Z+ heavy flavor (HF) events
  - Two step procedure
  - Apply HF-tagging to enrich the sample with heavy flavors
  - Subtract off the non-V+jet backgrounds from data
  - Exploit a discriminant with different shapes for b, c, and light jets
  - Extract the HF fraction by fitting data distribution with the templates

W + Jets Event Selection

- $W(\rightarrow l\nu)$ selection
  - Isolated lepton $p_T > 20$ GeV
  - Muon: $|\eta^{\mu}| < 1.7$
  - Electron: $|\eta^{e}| < 1.1$
    or $1.5 < |\eta^{e}| < 2.5$
  - Missing $E_T > 25$ GeV

- Jet selection
  - ≥ 1 jet
  - $p_T > 20$ GeV, $|\eta| < 1.1$

- Suppress multijet background and mis-reconstructed events

$$40\ \text{GeV} + \frac{1}{2}\not{E}_T < M_T < 120\ \text{GeV}$$

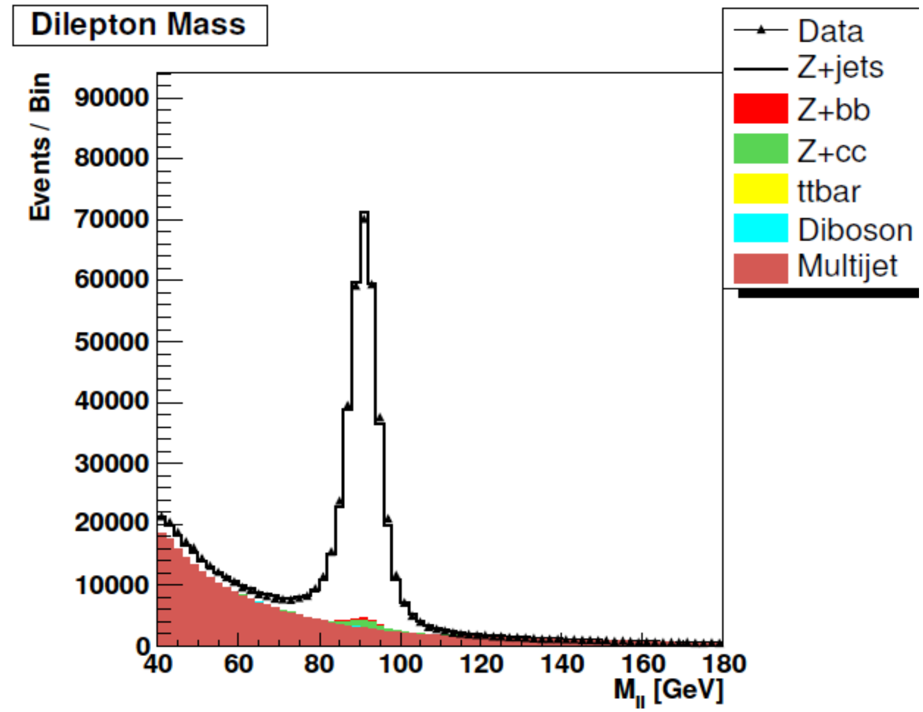
- 586k events in the e+μ channel

Z + Jets Event Selection

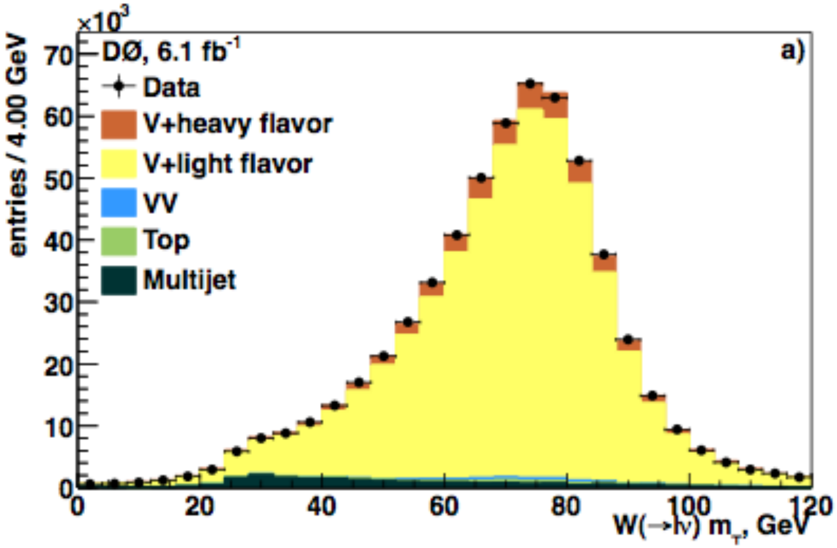
- $Z(\rightarrow ee/\mu\mu)$ selection
  - Isolated leptons $p_T > 20$ GeV
  - Muon: $|\eta^{\mu}| < 2.0$
  - Electron: $|\eta^{e}| < 1.1$ or $1.5 < |\eta^{e}| < 2.5$
  - $\geq$1 Central electron
  - 70 GeV $< M_{ll} <$ 110 GeV
- Jet selection
  - $\geq$ 1 jet
  - $p_T > 20$ GeV, $|\eta| < 2.5$
- Missing $E_T < 60$ GeV
  - Reduces the ttbar background by ~50%; minimal loss of Z+jets
- 94k (86k) events in $\mu\mu$ (ee) channel

Backgrounds

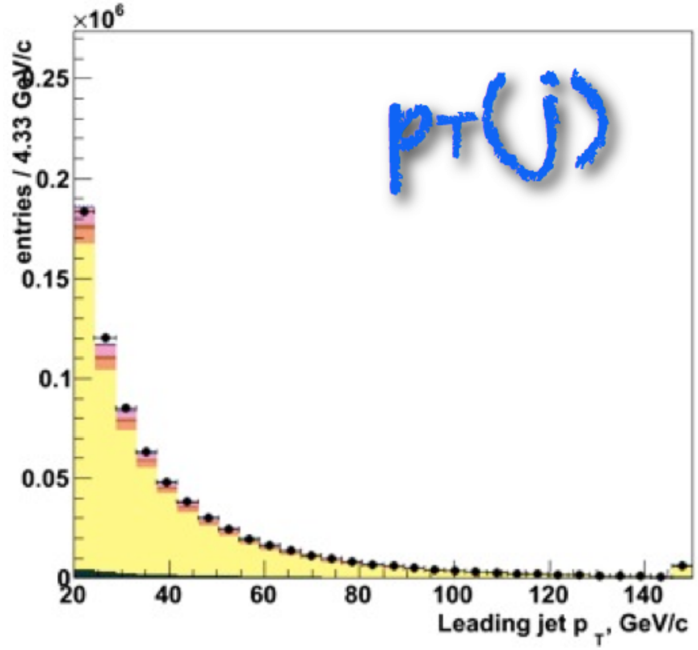
- Processes with real lepton(s) modeled via Monte Carlo
  - Pythia : WW/WZ/ZZ
  - CompHep: Single Top
  - Alpgen+Pythia: W/Z+jets
  - With GEANT-based detector simulation
- Normalization to higher order theory predictions
- Multijet background
  - A jet misidentified as a lepton
  - Estimated from multijet enriched data sample
  - Muon: reverse isolation criteria
  - Electron: relax EM quality criteria
  - Normalization obtained by fitting M_{ll} and $m_T(W)$ distribution



W+Jets Event Modeling



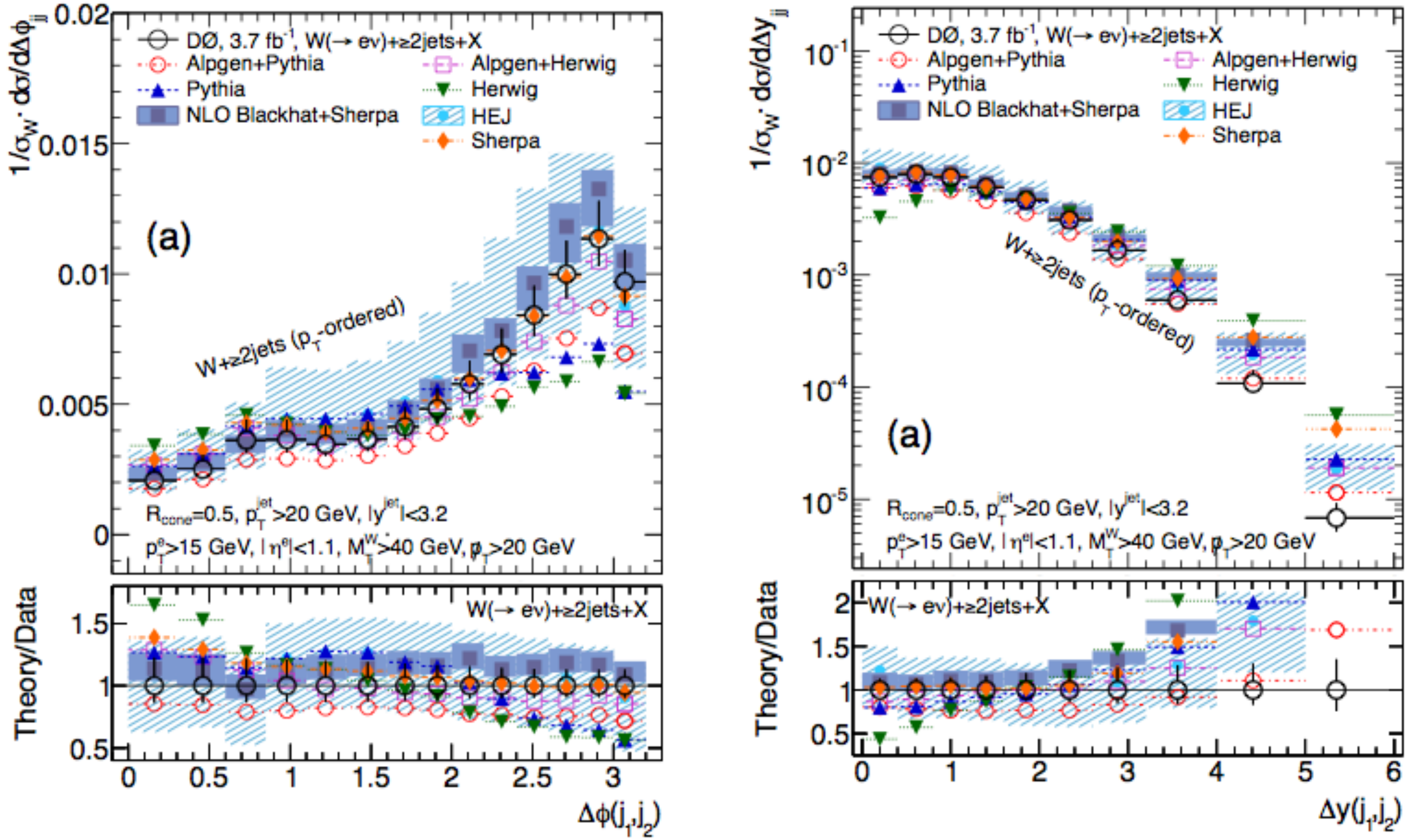
$$M_T^W = \sqrt{(\not{p}_T + p_T^e)^2 - (\not{p}_x + p_x^e)^2 - (\not{p}_y + p_y^e)^2}$$



- 586k candidate events
- Dominated by W+light jet events
- 5.2% background events
- Data well modeled by simulations

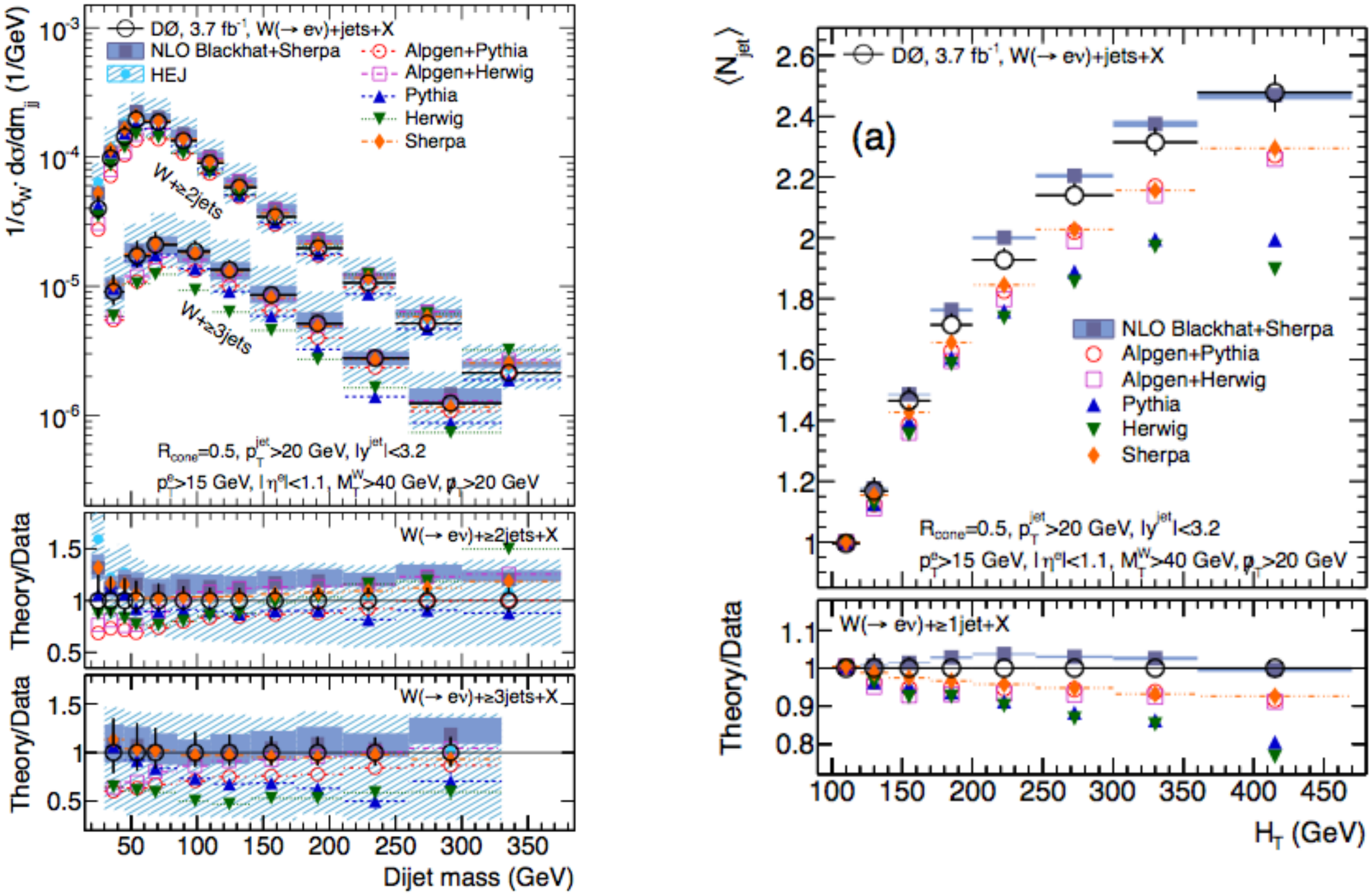
W+Jets Measurements

D0 : arXiv:1302.6508

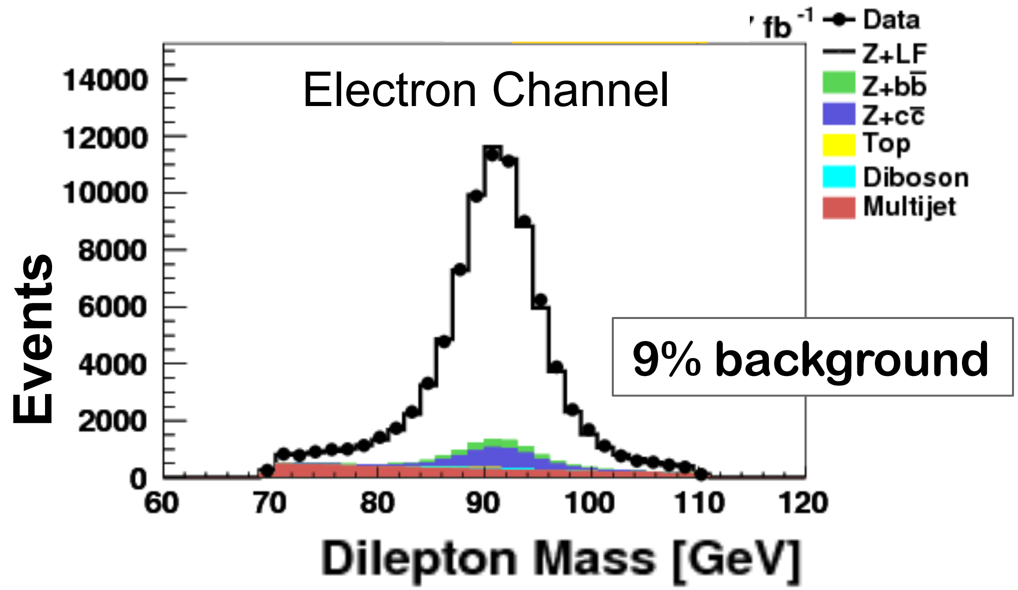


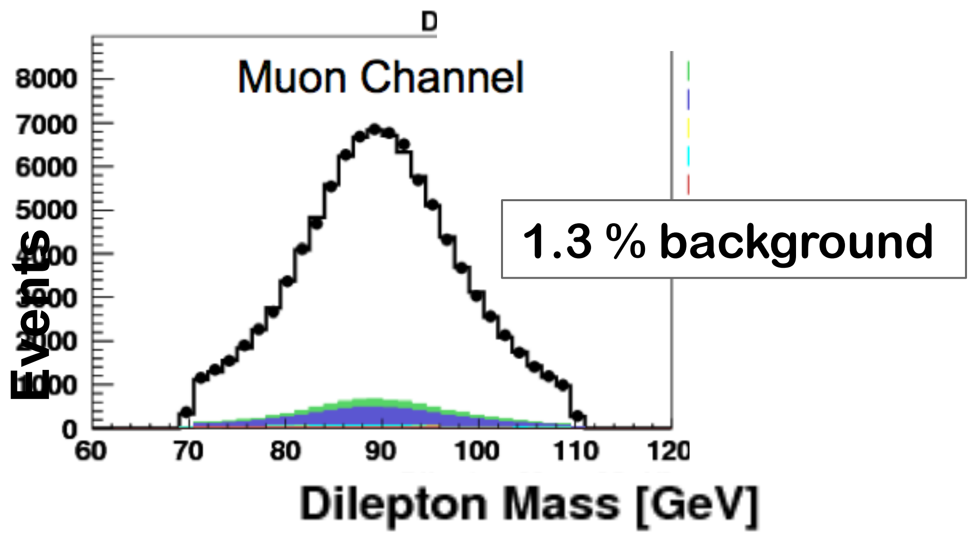
W+Jets Measurements

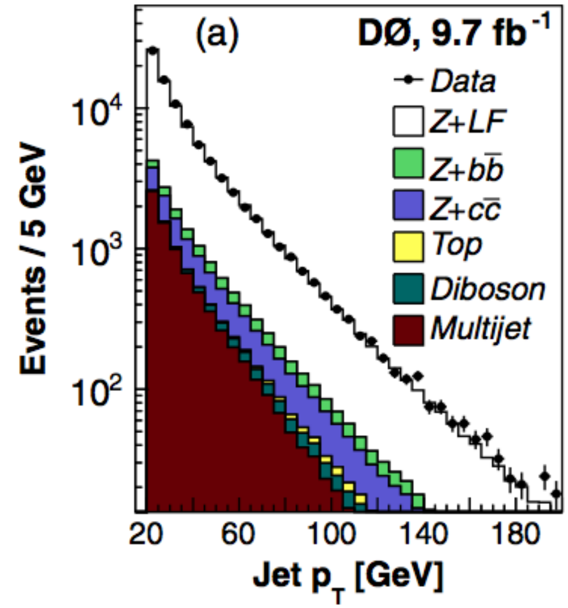
D0 : arXiv:1302.6508

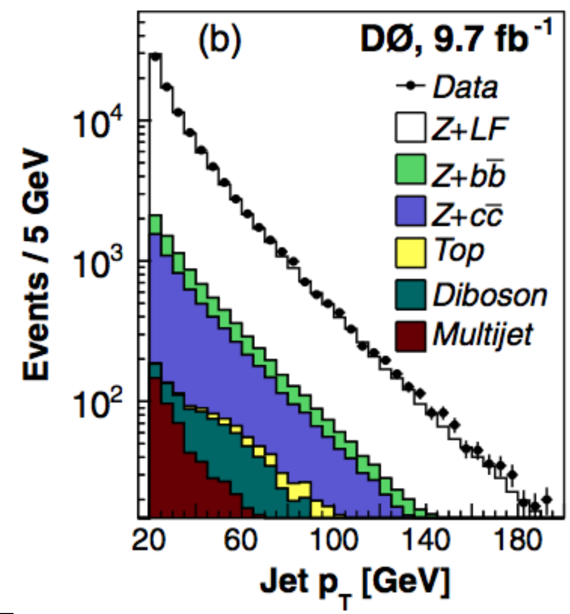


Z+Jets Event Modeling



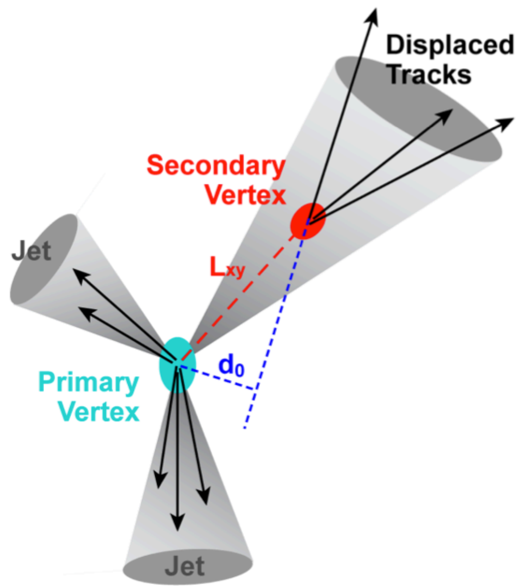


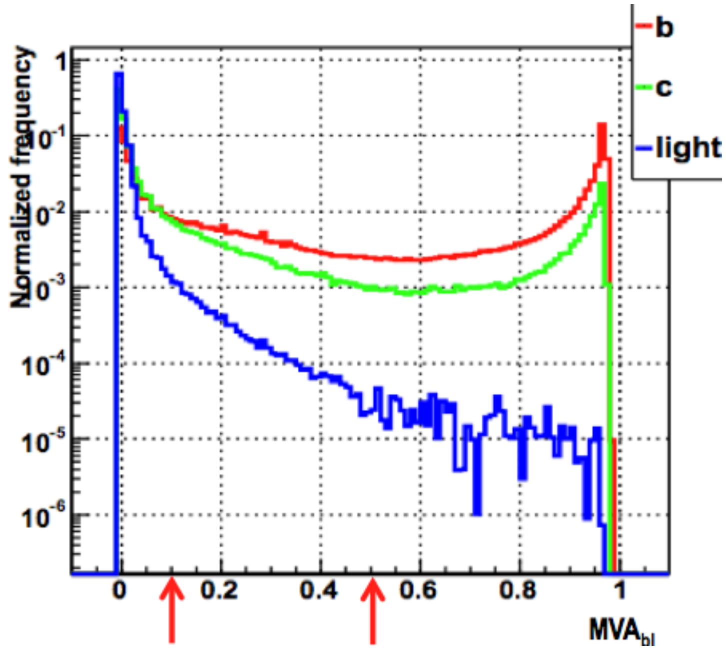




Heavy Flavor Jet Identification

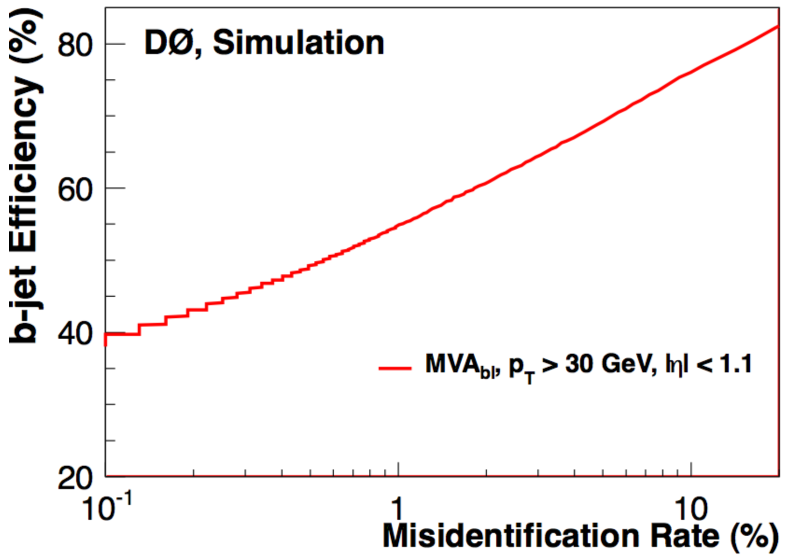
- B and C hadrons have a relatively long lifetime (~1 ps) and travel ~100-500μm before decay with large masses 2-5 GeV
  - Tracks displaced from primary vertex with large impact parameters

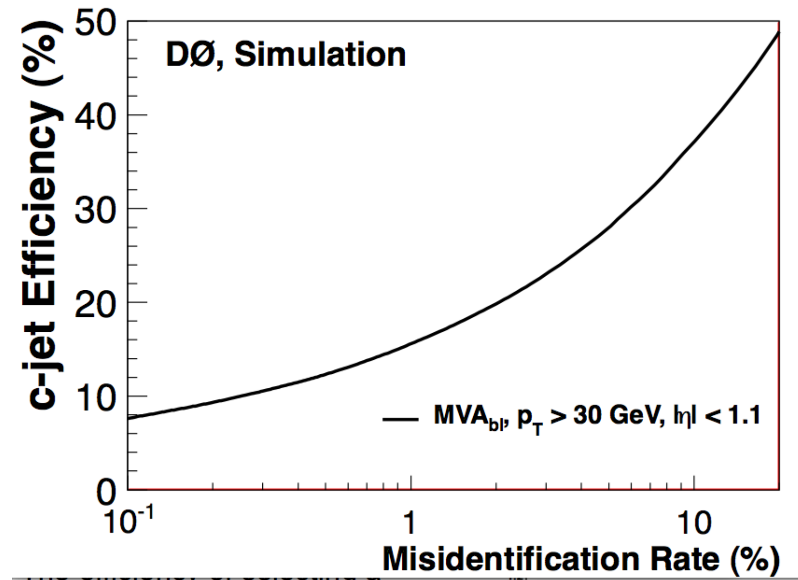




- Heavy flavor tagging exploits these characteristics of the tracks to create a discriminant used to enrich sample with HF-jets

Tagging Efficiency



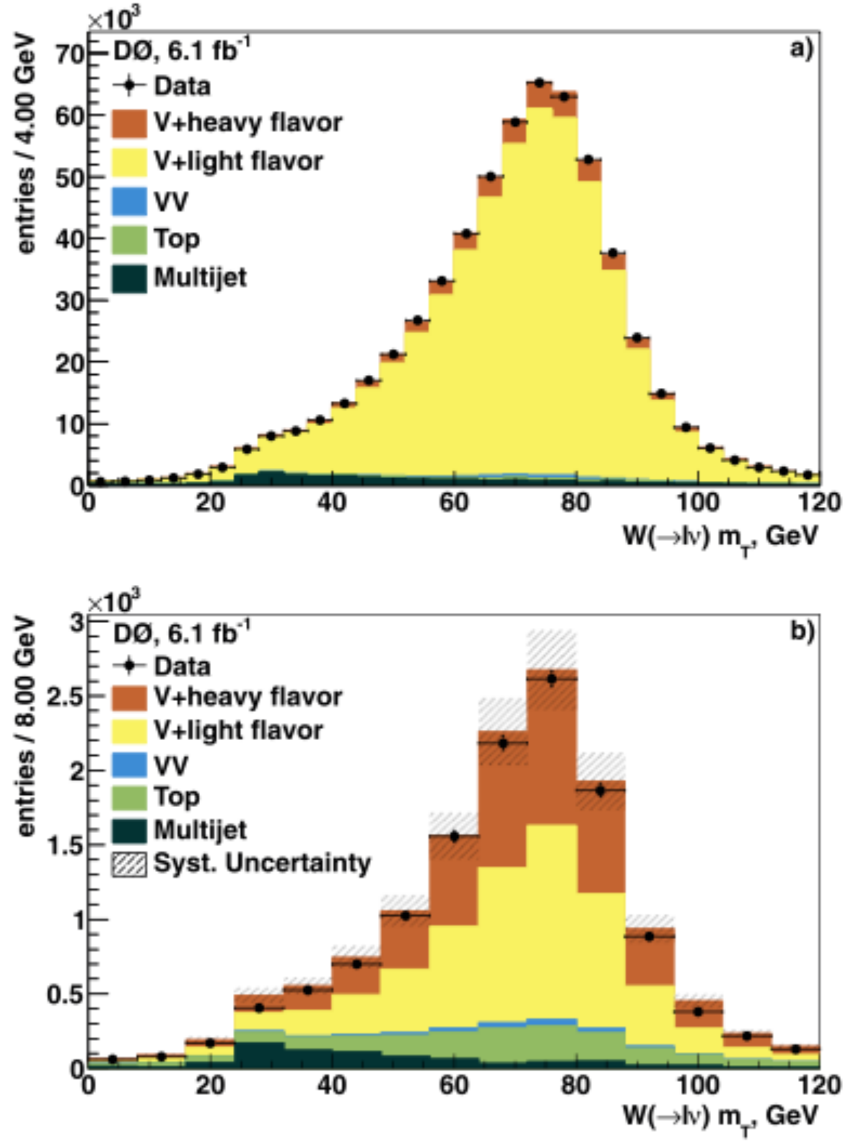


- The efficiency of jet to pass tagging selection is corrected to data
  - Data/MC corrections are derived from HF-enriched dijet samples
  - Parameterized in jet kinematics

Selection	ε_b	ε_c	ε_{light}
MVA_{BL}>0.1	58.5%	19.8%	2.4%
MVA_{BL}>0.5	40%	9%	0.24%

Impact of heavy flavor tagging

- Enrichment of sample with heavy flavors from W+b analysis

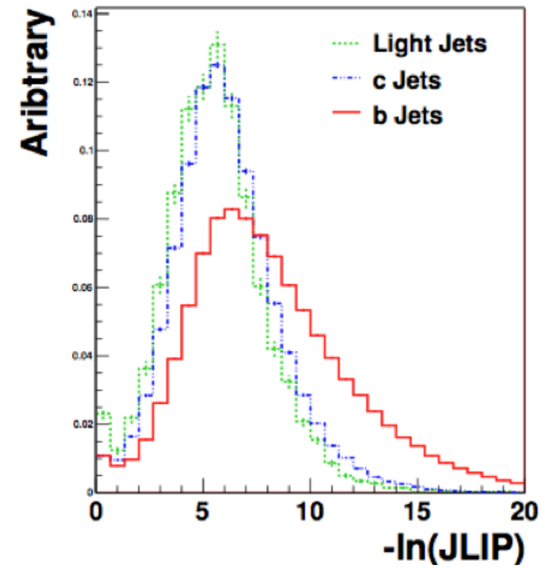


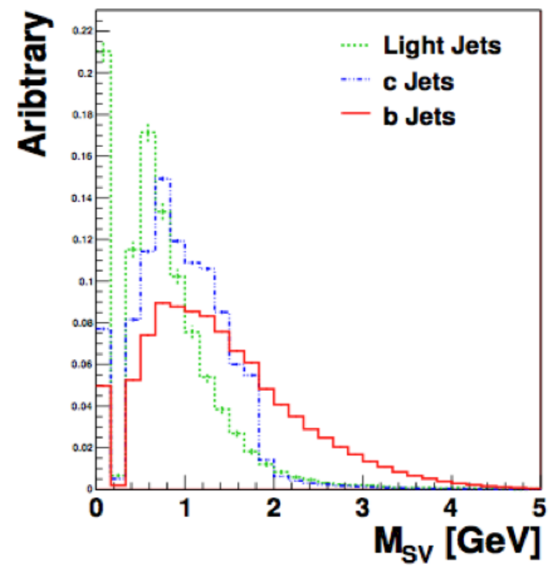
Estimation of Heavy Flavor Fraction

- The tagged sample still has some fraction of misidentified jets
- To further separate jets of different flavors, use a discriminant
  - M_{SVT} is invariant mass of tracks associated to secondary vertex
  - JLIP is jet lifetime impact parameter

$$D_{\mathrm{MJL}} = \frac{M_{\mathrm{svt}}/5 - ln(\mathrm{JLIP})/20}{2}$$

  - JLIP takes into account the geometry of the tracks in the event and M_{svt} takes into account event kinematics, providing pronounced discrimination
  - Stable performance with jet kinematics



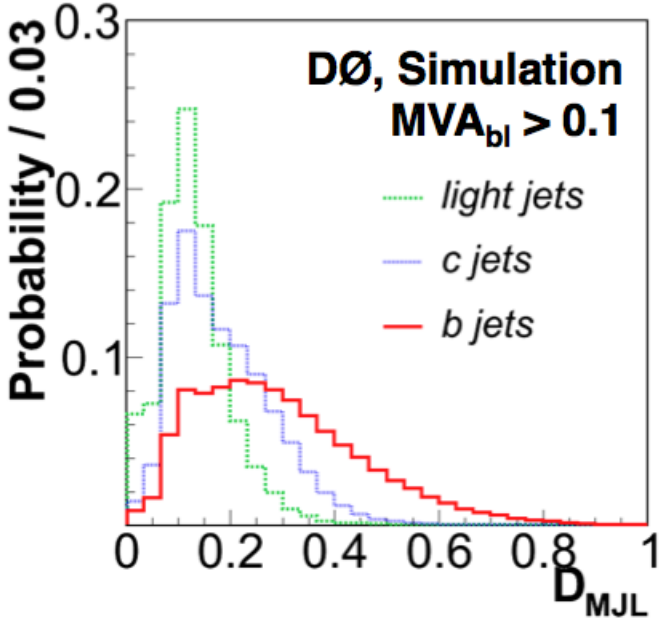


Estimation of Heavy Flavor Fraction-II

- The tagged sample still has some fraction of misidentified jets
- To further separate jets of different flavors, use a discriminant
  - M_{SVT} is invariant mass of tracks associated to secondary vertex
  - JLIP is jet lifetime impact parameter

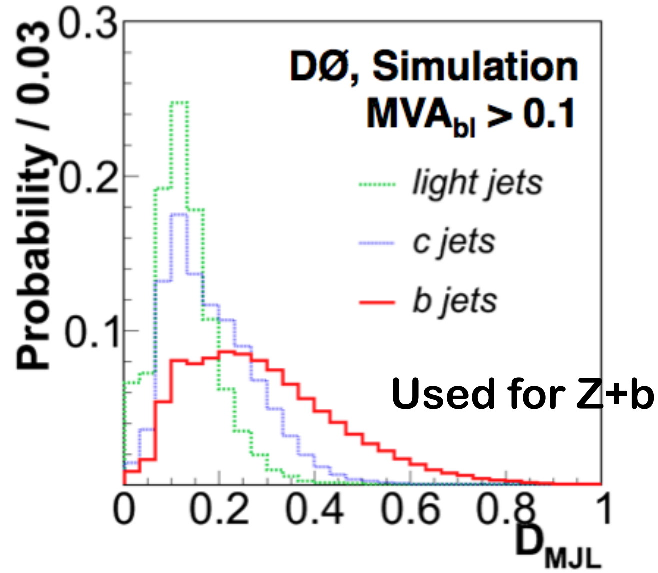
$$D_{\rm MJL} = \frac{M_{\rm svt}/5 - ln({\rm JLIP})/20}{2}$$

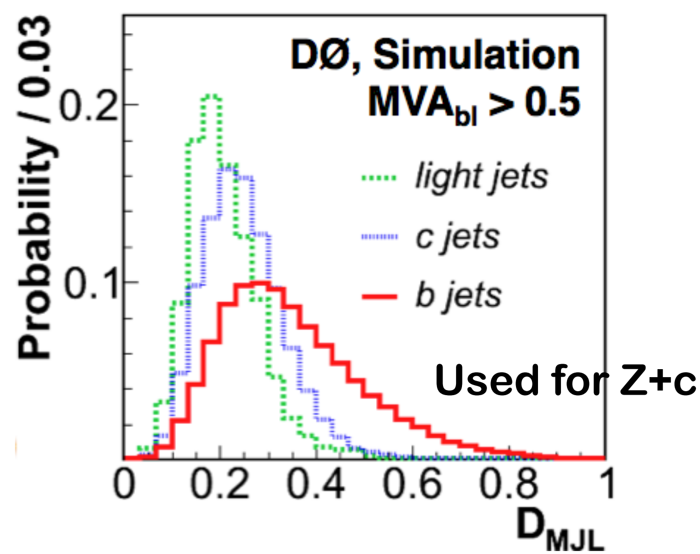
  - JLIP takes into account the geometry of the tracks in the event and M_{svt} takes into account vertex kinematics, providing pronounced discrimination
  - Stable performance with jet kinematics



Estimation of Heavy Flavor Fraction -III

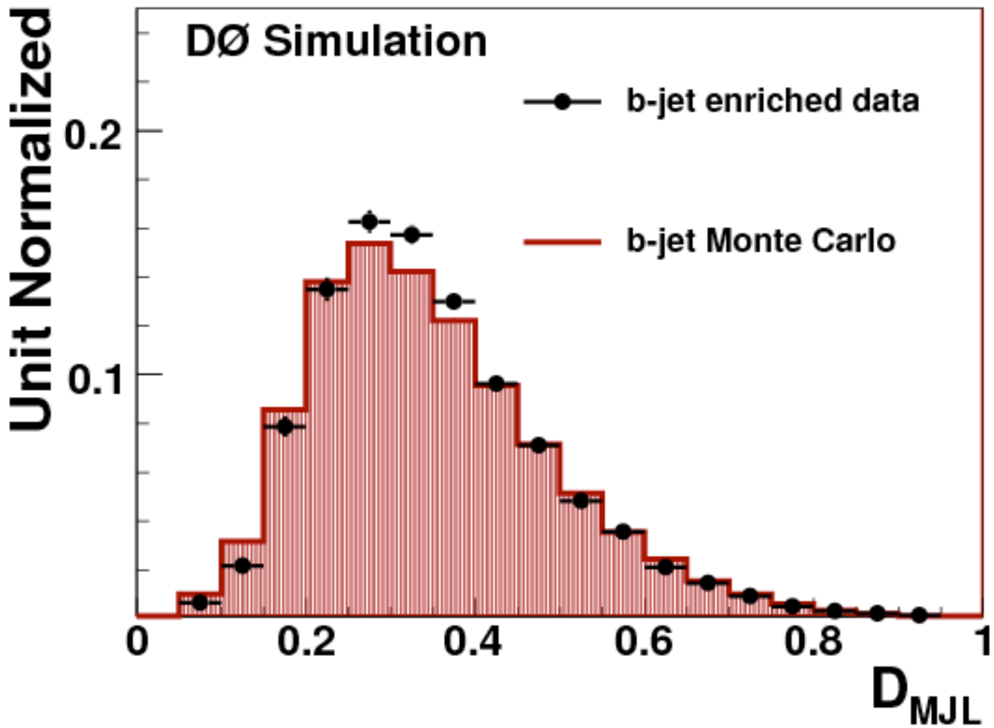
- Perform maximum likelihood fit to background subtracted data distribution with the templates to extract the jet flavor fractions
  - Works reliably for b-jet fraction
- Due to similarity in light and charm shapes, fit with b, c, and light jet templates returns large uncertainties for c-jet fraction
- With tighter tagging (suppression of light jets), light and c-jets start looking more similar, but separation between b vs c-jet remains intact.
  - Fit data with b- and c-jet templates after subtracting the residual contribution of light jets
  - Smaller uncertainty for c-jet fraction





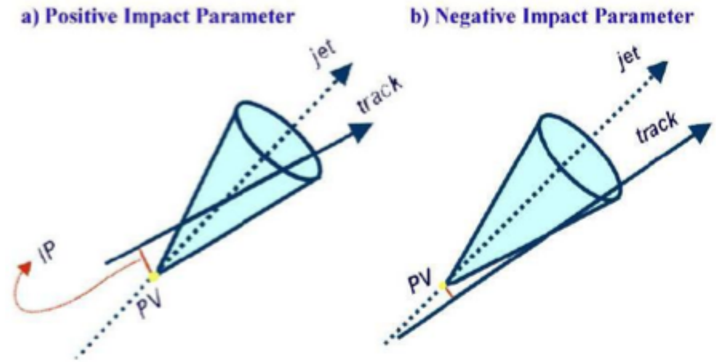
Modeling of Discriminant Templates

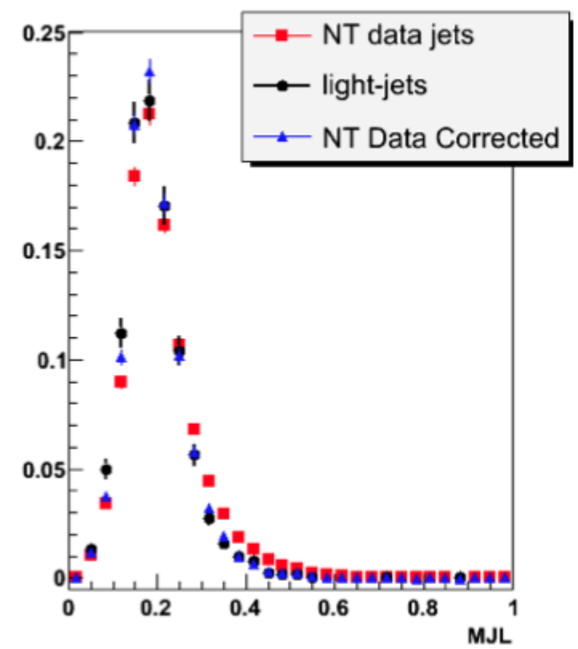
- Validate the simulation model of b-jet templates with b-jet enriched data sample
  - Double-tagged dijet events
  - One jet required to contain a muon from semi-leptonic B hadron decay
  - Away jet highly pure in b-jets



Modeling of Discriminant Templates

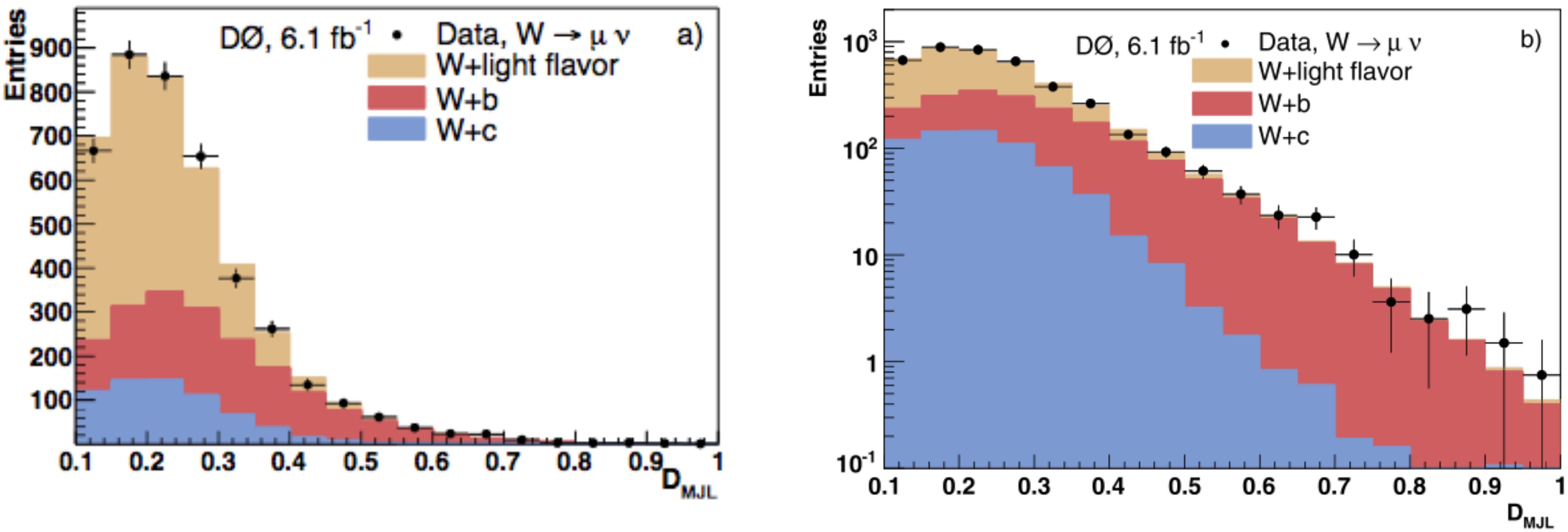
- Validate the simulation model of light-jet templates with light-jet enriched data sample (negatively tagged jets)
  - Jets that have negative values for some of the inputs like IP, decay length significance etc.
  - Subtract off the contamination from heavy flavor jets





Measurements of W+b jet Production

W+b-jet fraction



6.1 fb^{-1}	W→μν	W→eν
(Data – Bkg)	4127	6255
W+b fraction	0.30 ± 0.04	0.27 ± 0.03

W+b-jet Cross Section

$$\sigma(W+b)\cdot\mathcal{B}(W\to\ell\nu)=\frac{N_{W+b}}{\mathcal{L}\cdot\mathcal{A}\cdot\epsilon}$$

- N_{W+b} = No. of W+b-jet events
- L = Integrated Luminosity
- ε = combined selection efficiency
- A = acceptance

	W->μν	W->eν
D0	1.04 ± 0.05 (stat.) ± 0.12 (syst.)	1.00 ± 0.04 (stat.) ± 0.12 (syst.)
MCFM	1.34 [+0.41,-0.34]	1.28 [+0.41,-0.34]
SHERPA	1.21 ± 0.36	1.08 ± 0.32
MADGRAPH	1.52 ± 0.46	1.44 ± 0.43

$$\sigma(W+b)\cdot\mathcal{B}(W\to\ell\nu)=1.05\pm0.03\,(\text{stat.})\pm0.12\,(\text{syst.})\,\text{pb}$$

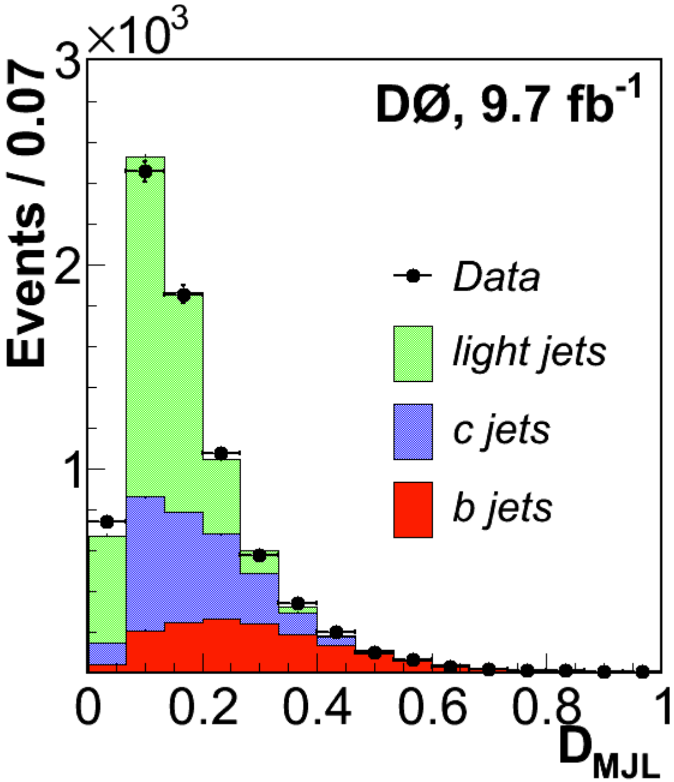
Measurements consistent with predictions within uncertainties

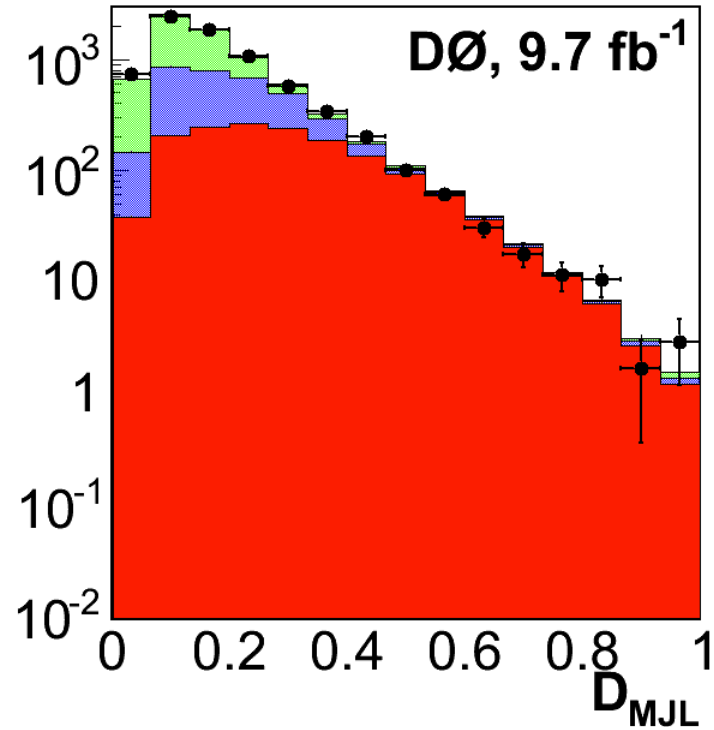
W+b-jet Cross Section

Systematics	σ (W+b+X) %
Jet energy calibration	5.6
b-tag efficiency	2.0
Lepton identification	2.0
Template Fitting	6.0
- Light templates - data	
- Merged heavy flavors	
- Background estimation	
Luminosity	6.1
Total	12

Measurements of Z+b jet Production

Z+b-jet fraction





For 9.7 fb^{-1}	Electron Channel	Muon Channel	Combined Channels
(Data – Bkg)	3,576	3,921	7,497
Z+b fraction	[19.8 ± 1.9]%	[21.5 ± 1.6]%	[20.8 ± 1.2]%

σ (Z+b jet) / σ (Z+jet)

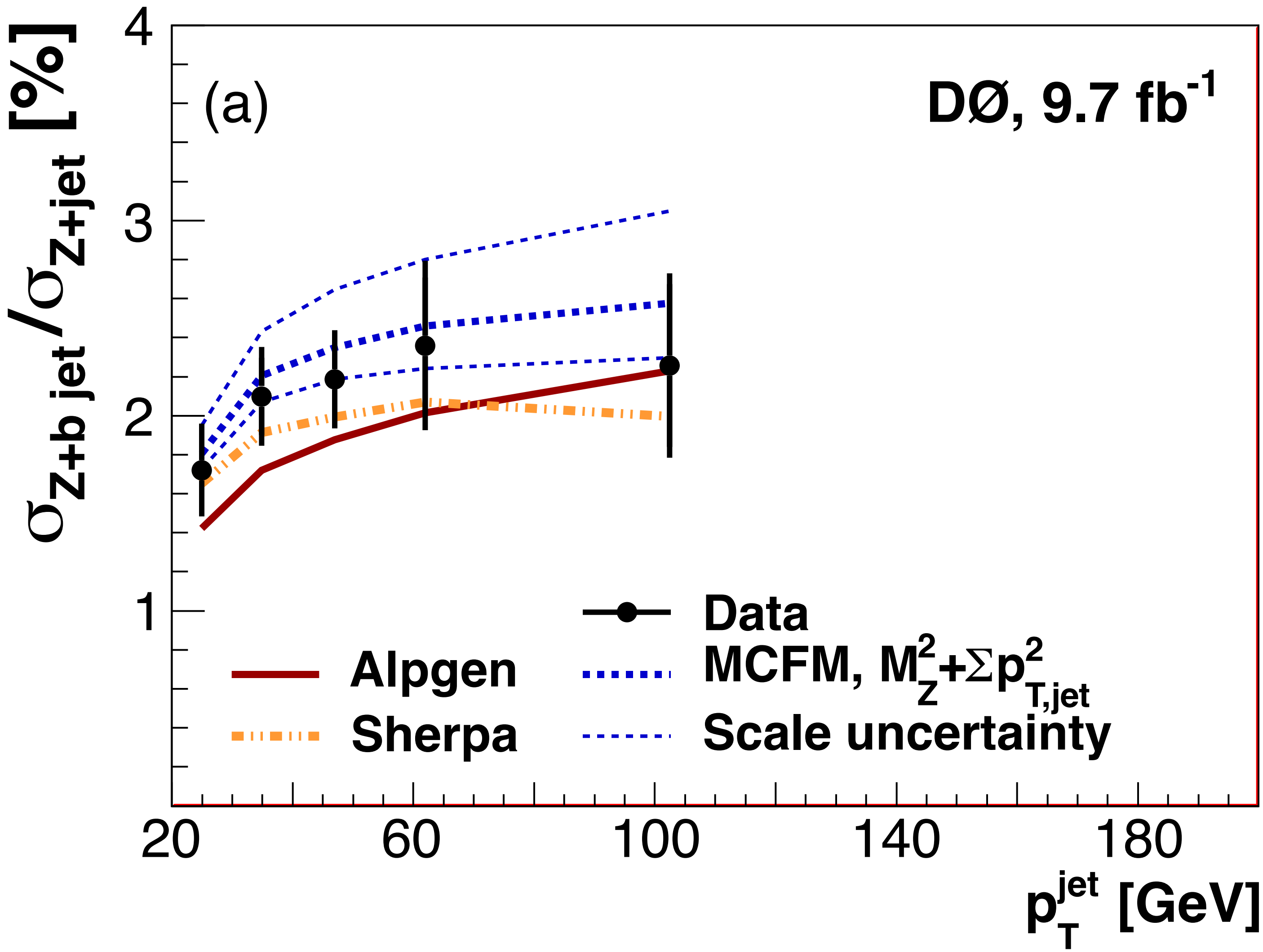
$$\frac{\sigma(Z+b\,\text{jet})}{\sigma(Z+\text{jet})} = \frac{N_{fitted}\, f_b}{N_{Z+j}\, \varepsilon^{b}_{btag}} \times \frac{A_{incl}}{A_b}$$

- Cancellation of many systematic uncertainties in the ratio
- Allows for precise comparison with theory calculations

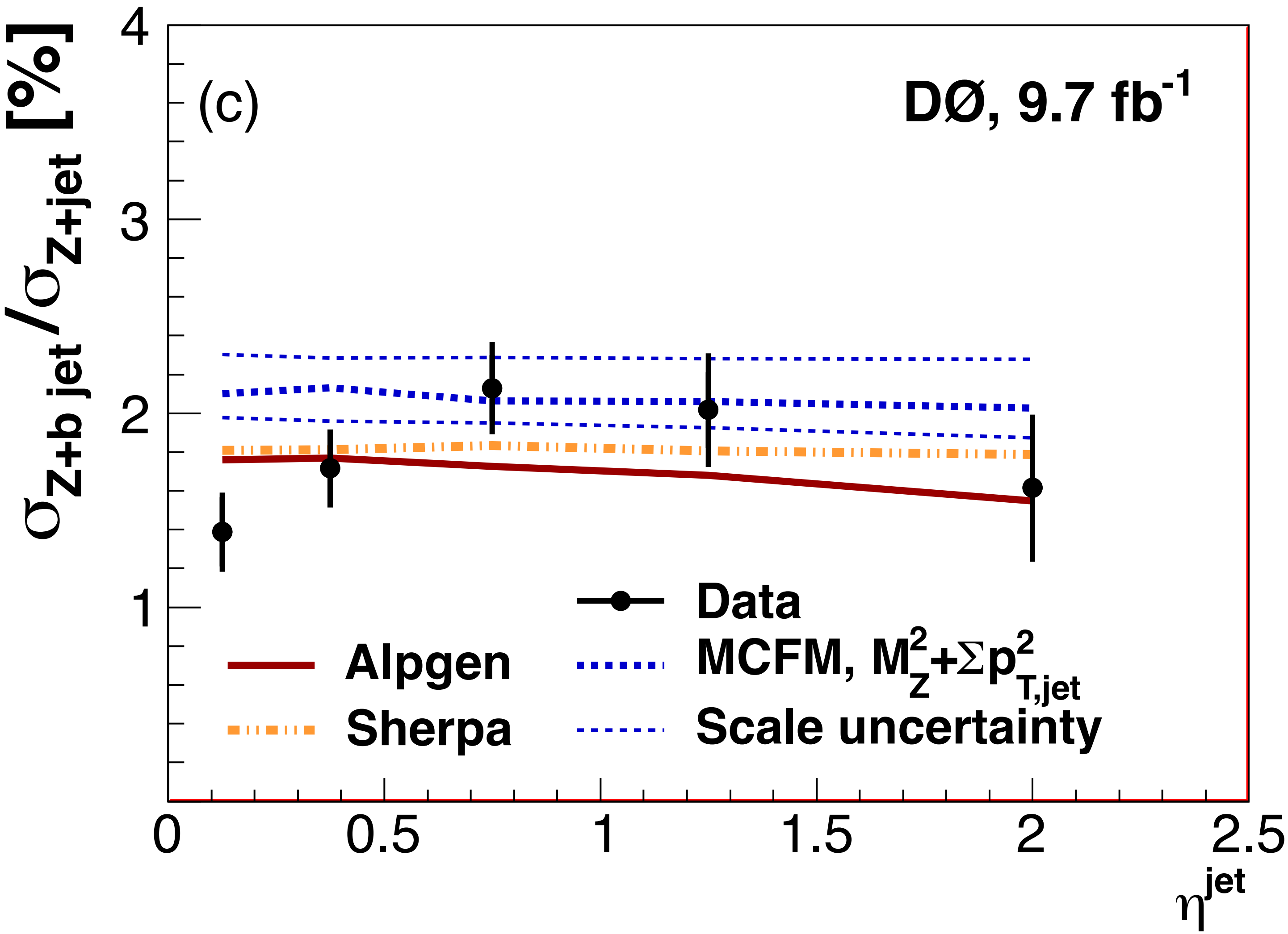
D0	**0.0196 ± 0.0012 (stat.) ± 0.0013 (syst.)**
CDF	**0.0208 ± 0.0018 (stat) ± 0.0027 (syst.)**
MCFM [MSTW2008, $M_Z^2+\Sigma(\text{jet } p_T)^2$ **]**	$0.0206^{+0.0022}_{-0.0013}$
ALPGEN+PYTHIA	**0.017**
SHERPA	**0.018**

Most precise measurement of the integrated ratio
Measurements consistent with the MCFM NLO predictions

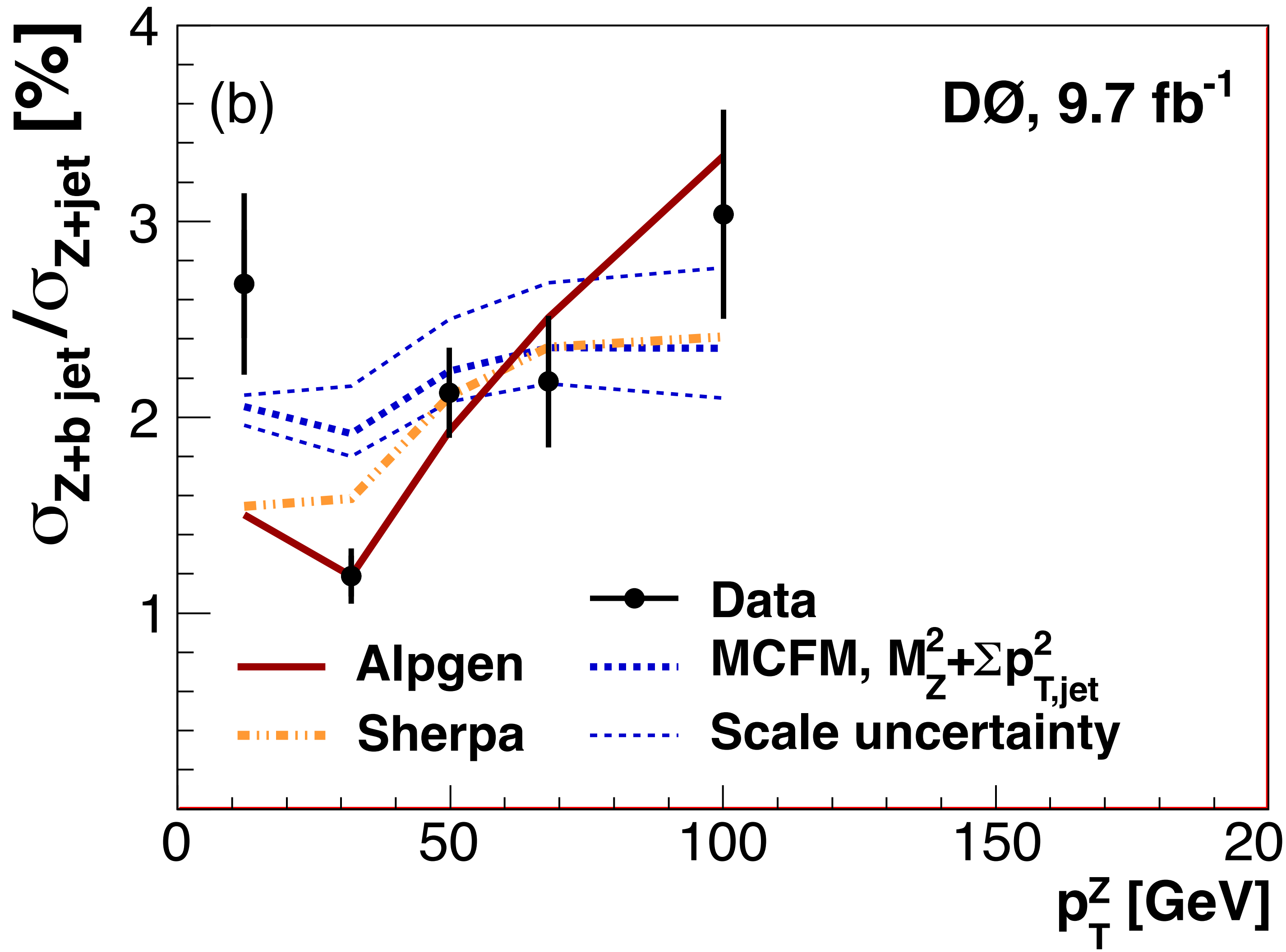
σ (Z+b jet) / σ (Z+jet) Dependence on Jet p_T



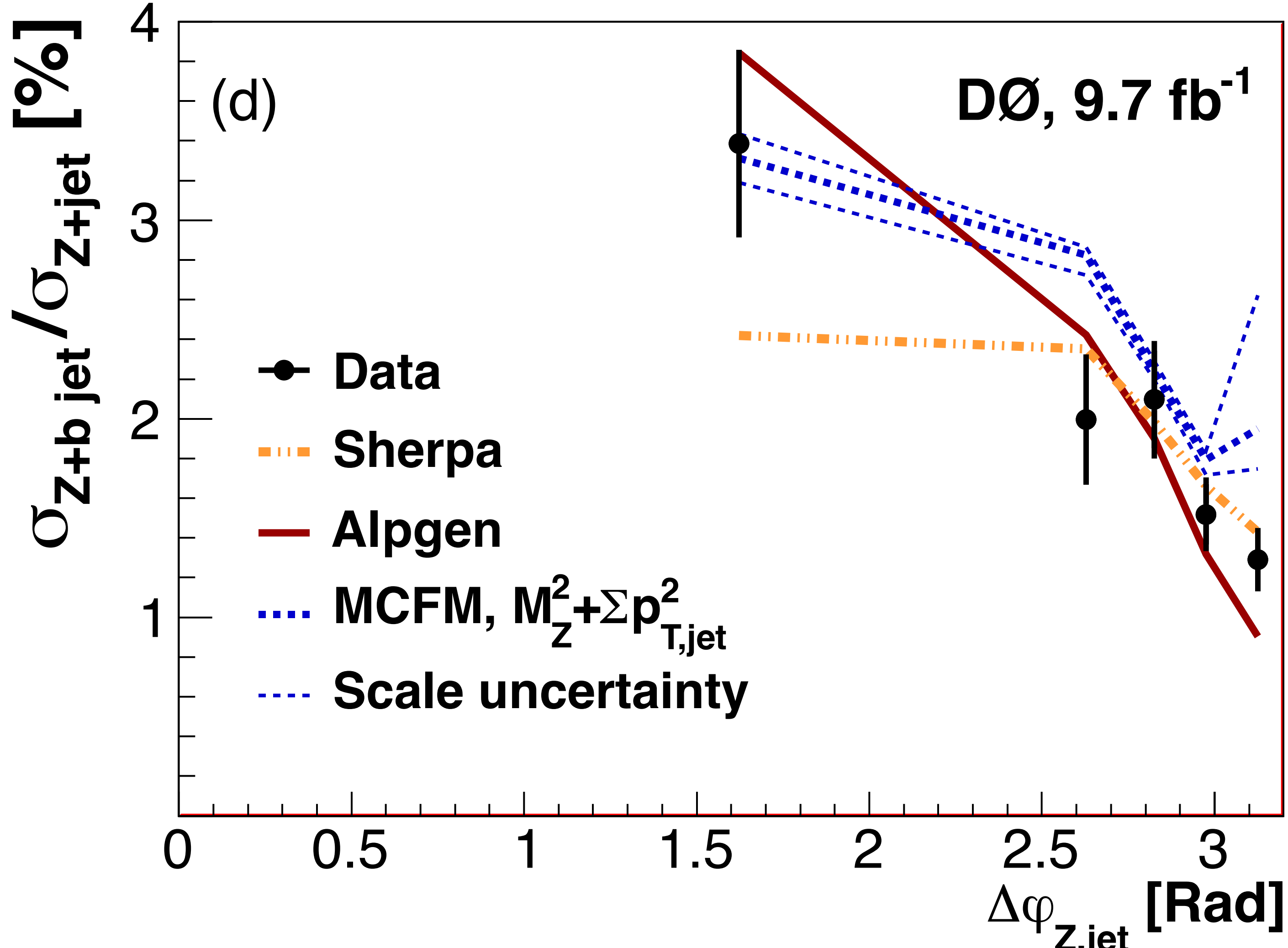
σ (Z+b jet) / σ (Z+jet) Dependence on Jet η



σ (Z+b jet) / σ (Z+jet) Dependence on Z p_T

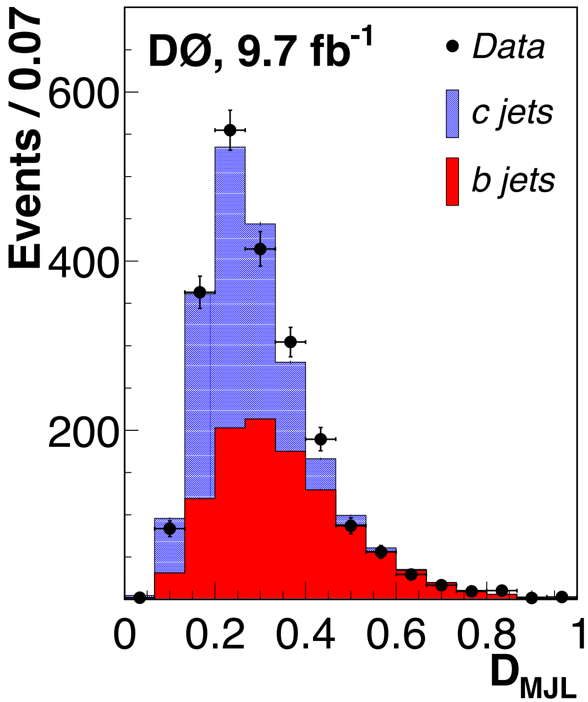


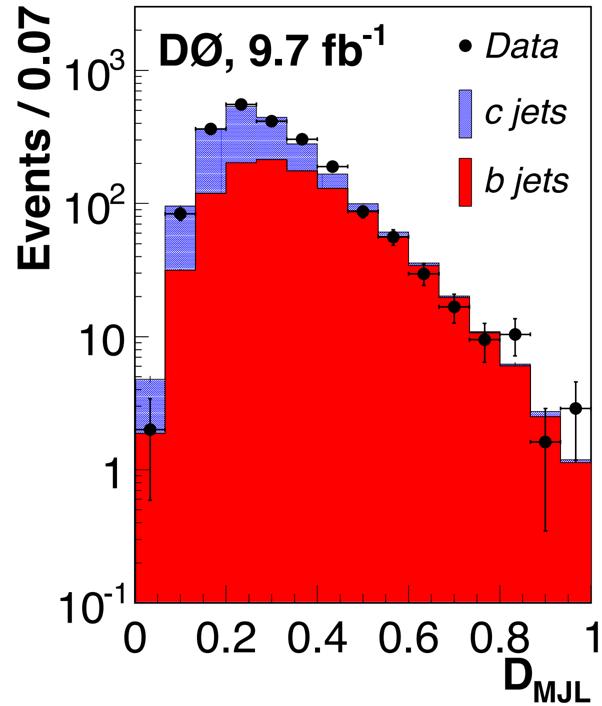
σ (Z+b jet) / σ (Z+jet) Dependence on $\Delta\,\phi$ (Z, jet)



Measurements of Z+c jet Production

Z+c-jet fraction





For 9.7 fb^{-1}	Muon and Electron Channels
(Data-bkg) Events	2125
Z+b jet fraction	[51.4 ± 2.8] %
Z+c jet fraction	[48.6 ± 2.8] %

σ (Z+c jet) / σ (Z+jet)

$$\frac{\sigma(Z + c\ \mathrm{jet})}{\sigma(Z + \mathrm{jet})} = \frac{N_{fitted}\ f_c}{N_{Z+j}^{presel}\ \ \epsilon_{tag}^{c}} \times \frac{\mathcal{A}_{incl}}{\mathcal{A}_c}$$

- **Cancellation of many systematic uncertainties in the ratio**
- **Allows for precise comparison with theory calculations**

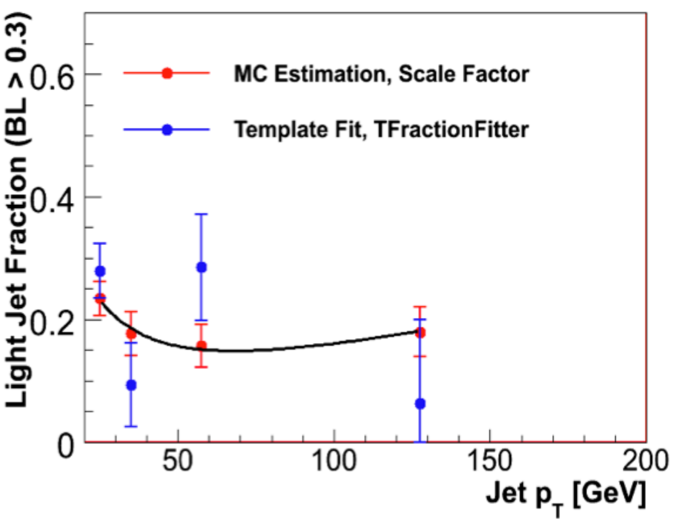
D0	0.0829 ± 0.0052 (stat.) ± 0.0089 (syst.)
MCFM [MSTW2008, $Q^2 = M_Z^2 + \Sigma(\text{jet } p_T)^2$	$0.0368^{+0.0063}_{-0.0039}$
MCFM [IC model, CTEQ6.6c]	$0.0425^{+0.0048}_{-0.0029}$
ALPGEN	**0.0223**
SHERPA	**0.0397**

First measurement of Z boson in association with c-jet
Measurements significantly in excess of predictions

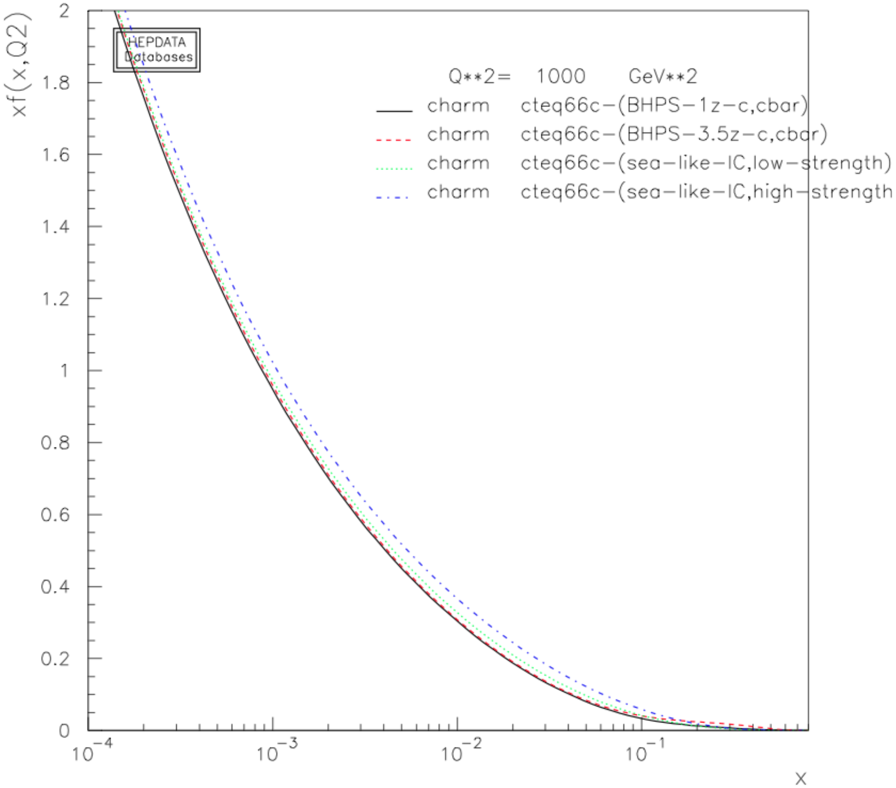
Systematic Uncertainties

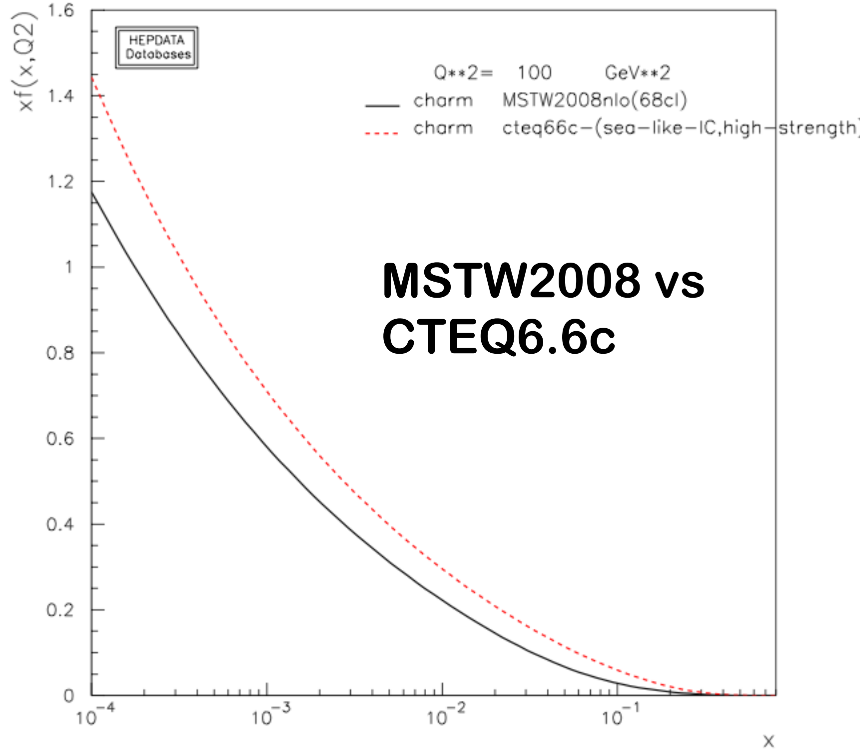
Systematics	σ (Z+c)/ σ (Z+j) %
Jet energy calibration	3.4
Heavy flavor enrichment	1.9
Template Shape	5.5
--Light templates - data	
-- Merged heavy flavors	
--Background estimation	
Light jet subtraction	8.1
Total	10.6

Systematics on Z+light jet subtraction determined by comparing the light jet fraction extracted from fitting data and estimated from data corrected MC



HEP Data Durham Page

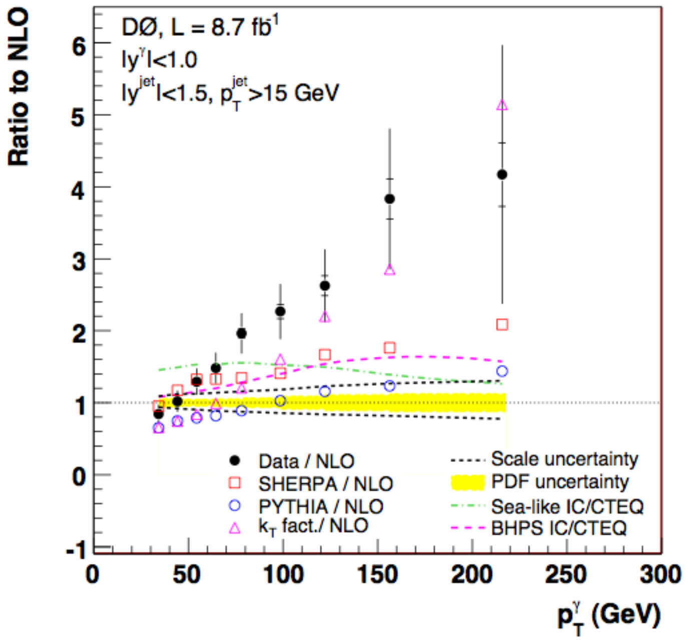


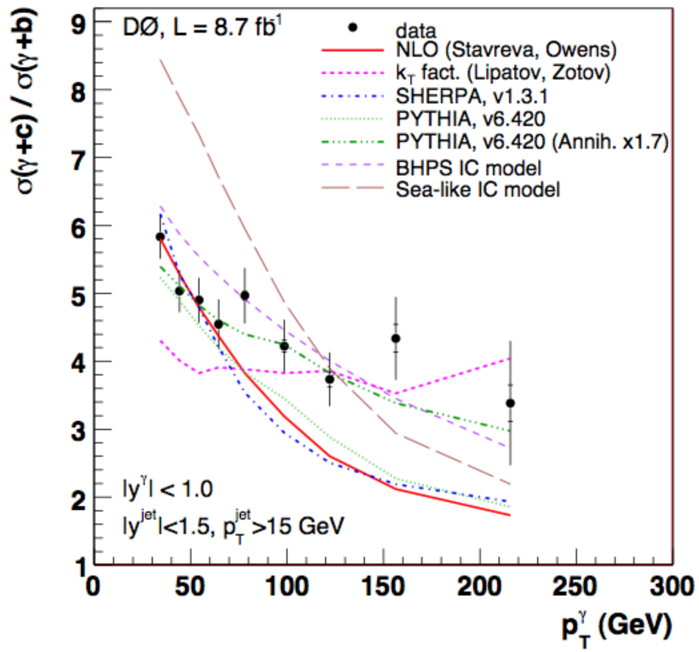


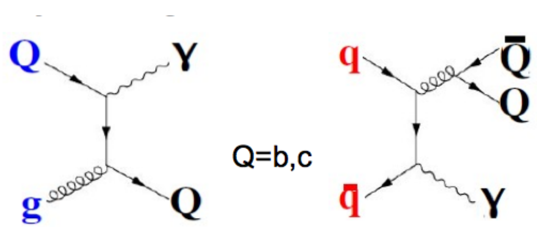
IC parameterizations implemented in CTEQ6.6c PDFs

Consider the highly enhanced Sea-like IC model with MCFM predictions for comparison

Photon + c : PLB 719, 354 (2013)







IC models predicted higher cross sections. BHPS model favored with rise in photon p_T.

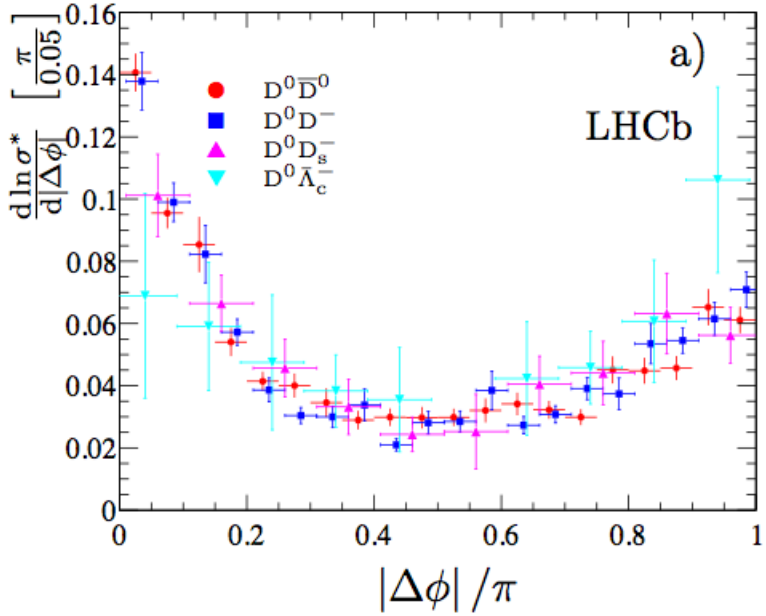
g→c cbar splitting

LEP results suggested underestimation in the g->cc rates by about a factor of 2. PDG PLB 667, 2008, p 209

Table 17.2: Measured fraction of events containing $g \to c\bar{c}$ and $g \to b\bar{b}$ subprocesses in Z decays, compared with theoretical predictions. The central/lower/upper values for the theoretical predictions are obtained with $m_c = (1.5 \pm 0.3)$ and $m_b = (4.75 \pm 0.25)$ GeV.

	$\overline{n}_{g\to c\bar{c}}$ (%)	$\overline{n}_{g\to b\bar{b}}$ (%)
ALEPH	[133] $3.26 \pm 0.23 \pm 0.42$	[153] $0.2777 \pm 0.042 \pm 0.057$
DELPHI		[154] $0.21 \pm 0.11 \pm 0.09$
L3	[155] $2.45 \pm 0.29 \pm 0.53$	
OPAL	[156] $3.20 \pm 0.21 \pm 0.38$	
SLD		[157] $0.307 \pm 0.071 \pm 0.066$
Theory [151]		
$\Lambda^{(5)}_{\overline{\rm MS}} = 150$ MeV	$1.35^{+0.48}_{-0.30}$	0.20 ± 0.02
$\Lambda^{(5)}_{\overline{\rm MS}} = 300$ MeV	$1.85^{+0.69}_{-0.44}$	0.26 ± 0.03

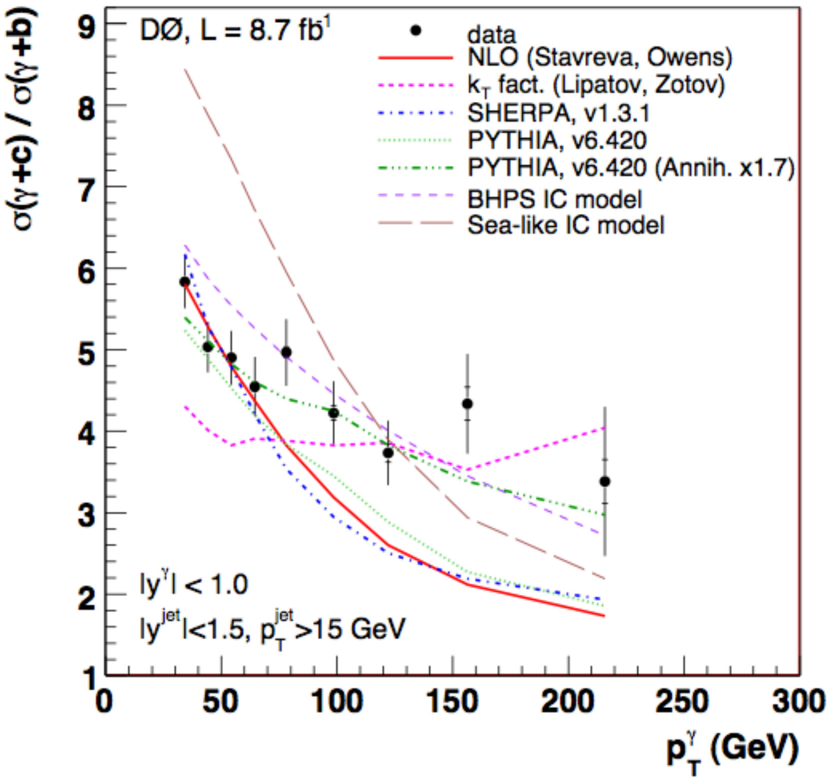
Observation of double charm production arXiv:1205.0975



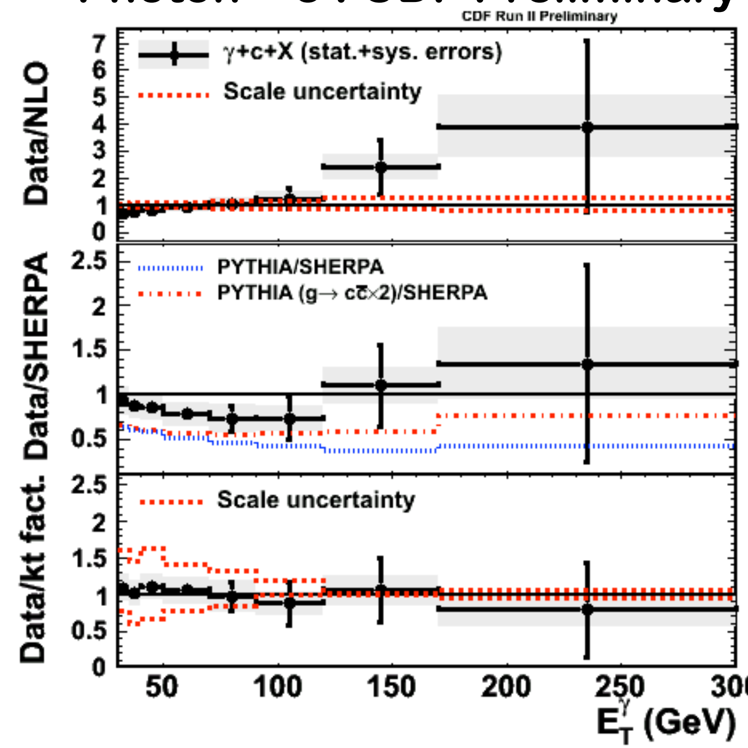
For $C\overline{C}$ events significant rapidity and azimuthal correlations are observed. These, as well as the invariant mass spectra for $C\overline{C}$ events, suggest a sizeable contribution from the gluon splitting process to charm quark production [38].

Enhanced g→cc splitting

Photon + c : PLB 719, 354 (2013)

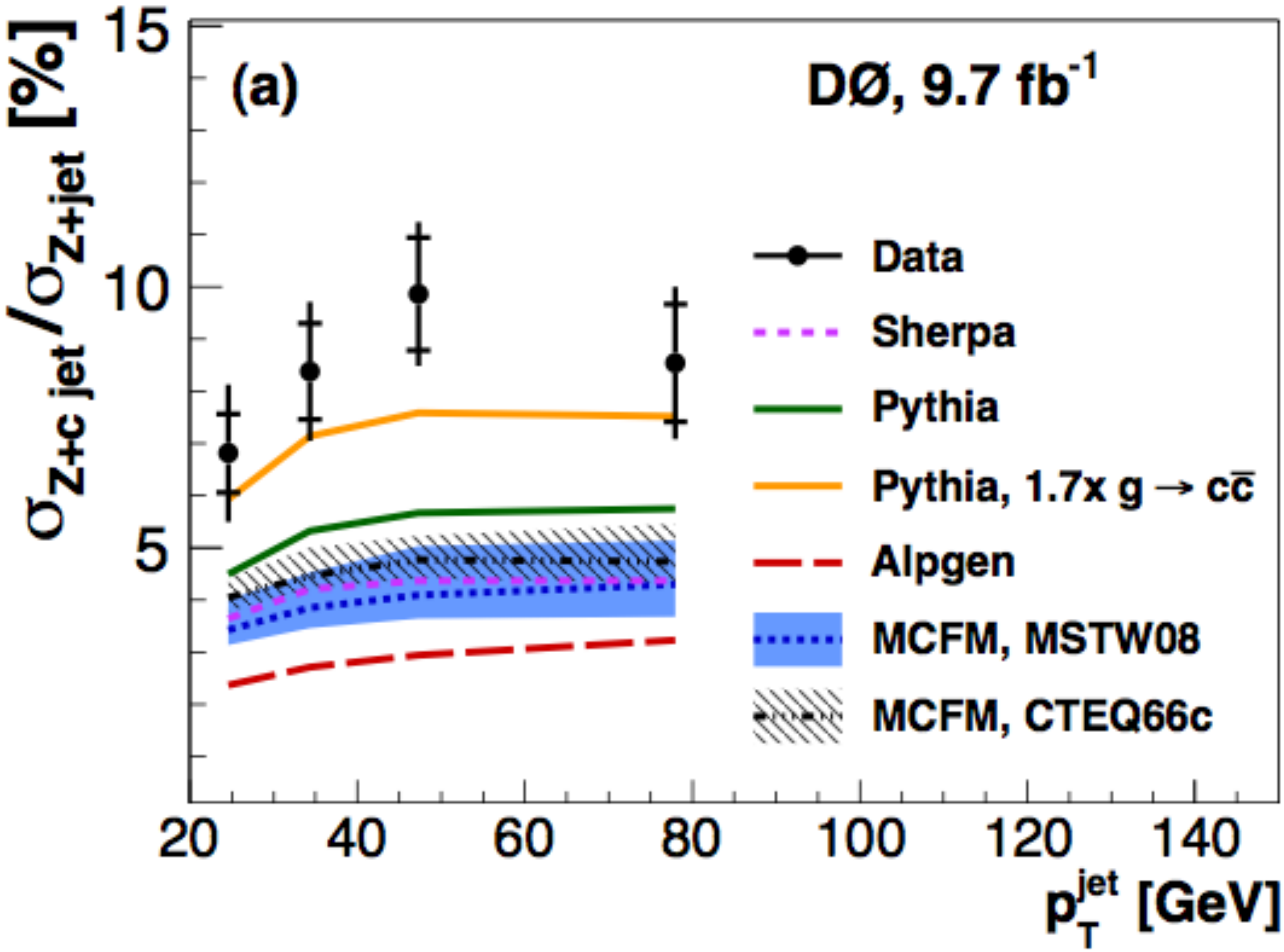


Photon + c : CDF Preliminary

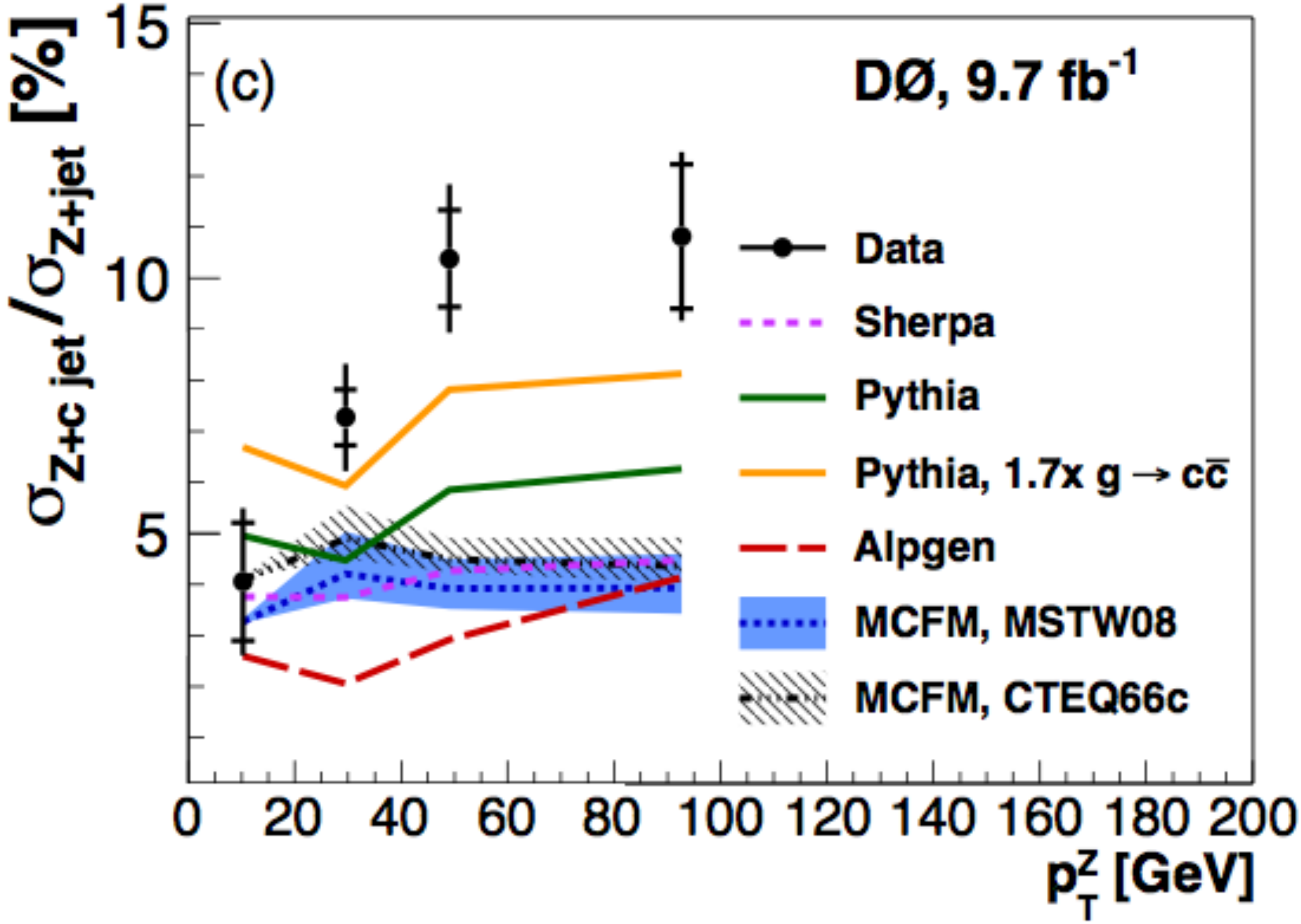


Measurements of photon + charm production supports the previous observation.
Measurements showed improved description with Pythia predictions using enhanced g→cc splitting (increased rates of annihilation process).

σ (Z+c jet) / σ (Z+jet) Dependence on Jet p_T



σ (Z+c jet) / σ (Z+jet) Dependence on Z p_T



σ (Z+c jet) / σ (Z+b-jet)

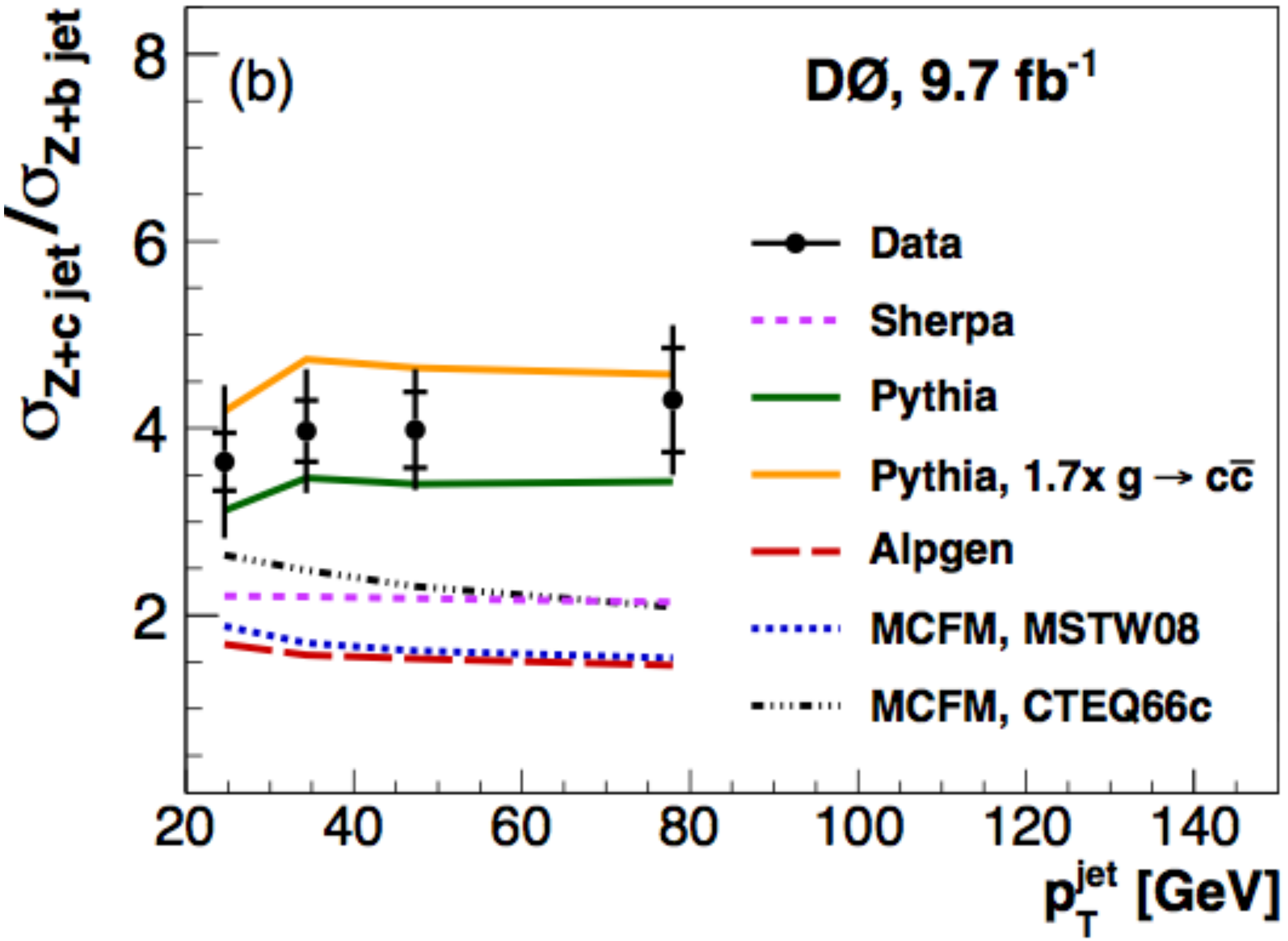
$$\frac{\sigma(Z + c \text{ jet})}{\sigma(Z + b \text{ jet})} = \frac{f_c \ \epsilon^b_{tag}}{f_b \ \epsilon^c_{tag}} \times \frac{\mathcal{A}_b}{\mathcal{A}_c}$$

- **Cancellation of many systematic uncertainties in the ratio**
- **Allows for precise comparison with theory calculations**

D0	4.00 ± 0.21 (stat.) ± 0.58 (syst.)
MCFM [MSTW2008, $M_Z^2+\Sigma(\text{jet } p_T)^2$	1.64
MCFM [IC model, CTEQ6.6c]	2.23
ALPGEN	**1.57**
SHERPA	**2.19**

Measurements significantly in excess of predictions

σ (Z+c jet) / σ (Z+b-jet) Dependence on Jet p_T



Cross Checks

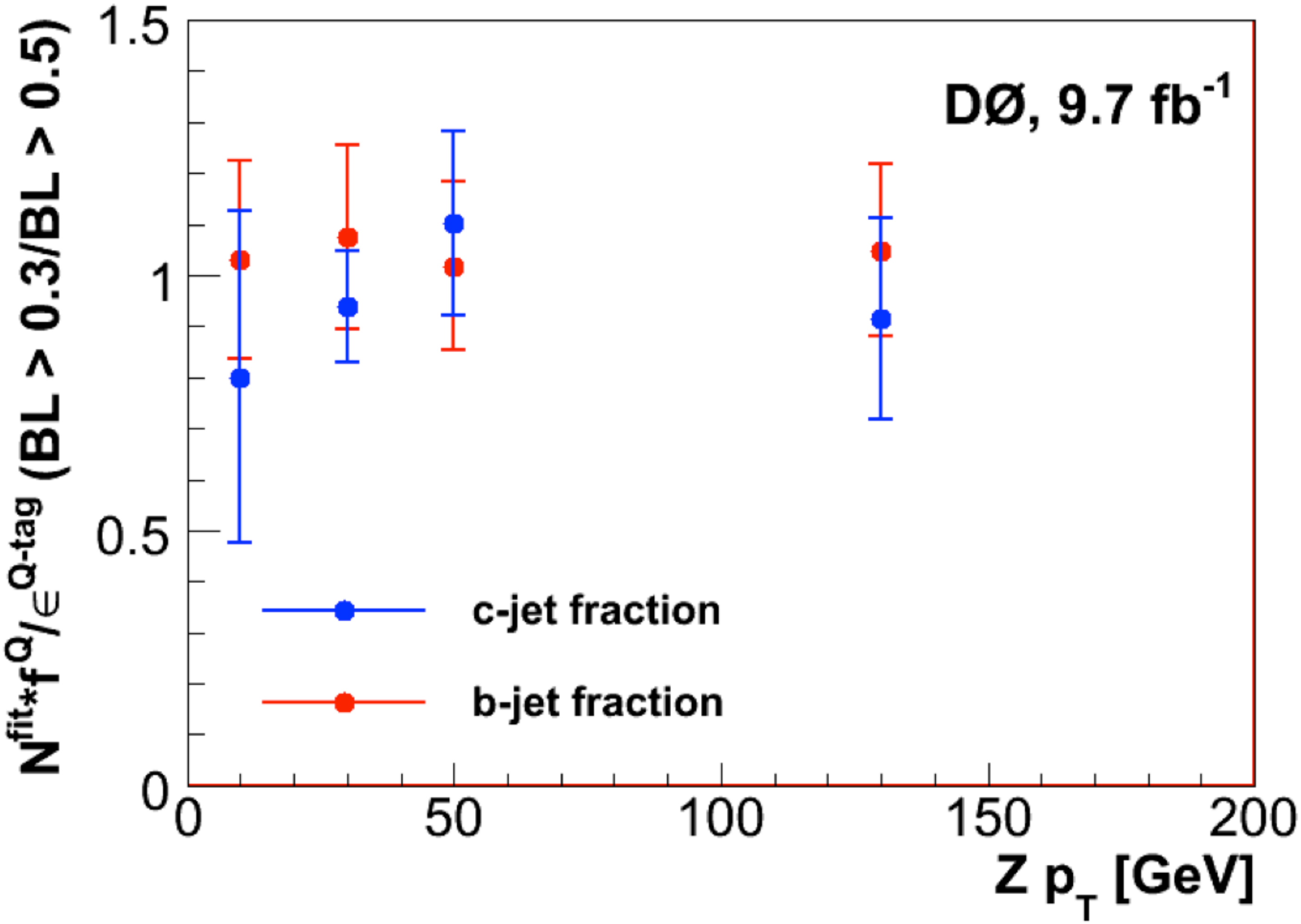
- A series of careful cross-checks were done to validate the results which yielded consistent results within uncertainties
- Measurements in the two leptonic channels
- Measurements with different tagging selections allowing for varied light jet contribution
- Measurement of σ(Z+b)/σ(Z+jet) with the extracted fraction agrees with the previously measured value
- Measurement with Secondary Vertex Mass templates only
- Solve system of equations where σ(Z+b)/σ(Z+jet) is fixed to the measured value provided consistent results

$$\frac{N^{Z+b}}{N^{Z+b}+N^{Z+c}+N^{Z+l}} = 2.02\%$$

$$N_{\text{before b-tag}} = t'_b N_b + t'_c N_c + t'_\ell N_\ell$$

$$N_{\text{b-tagged}} = \bar{\epsilon}_b t'_b N_b + \bar{\epsilon}_c t'_c N_c + \bar{\epsilon}_\ell t'_\ell N_\ell,$$

Cross Checks



Conclusions-I

- Vector boson + heavy flavor jet production provides a good laboratory for precision tests of pQCD and probes the heavy flavor content of the proton
- Understanding of these processes key for the New Phenomena searches
- Many interesting results from the D0 experiment
  - Extend the previously probed phase space
  - Test various predictions from theory and simulation
- W+b-jet
  - Precise measurement of cross section
  - Reasonable agreement with theory within uncertainties

Conclusions-II

- σ (Z+b jet)/ σ (Z+jet)
  - Most precise measurement in agreement with theory
  - First measurement of the ratio of differential cross sections
  - Provides valuable feedback to MC builders and theorists
  - Tension is observed in Z p_T, jet η, and $\Delta \phi_{Z,jet}$

- σ (Z+c jet)/ σ (Z+jet) , σ (Z+c jet)/ σ (Z+b-jet)
  - The first observation of Z+c jet production
  - Measured ratios of integrated and differential cross sections
  - Significant disagreements observed with NLO predictions
  - PYTHIA with enhanced $g \rightarrow cc$ splitting provides the best description (also supported by photon+c measurements)

- Tevatron measurements have pioneered the study of W,Z +HF jets.
  - The higher statistics at LHC will extend measurements in complementary kinematic regions. Also improved V+HF models with benefit the analyses at LHC.

Thanks for your attention!